SPECIAL SECTION: LAND USE OPTIONS IN DRY TROPICAL WOODLAND ECOSYSTEMS IN ZIMBABWE

The value of mature trees in arable fields in the smallholder sector, Zimbabwe

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Abstract

In the smallholder sector of much of Africa, mature trees are often left in arable fields or on field margins, and there is often a conflict between extension staff, who prescribe the removal of all trees, and farmers, who, traditionally, leave trees scattered in fields. Using data on tree-crop interactions from Zimbabwe, we have used the STELLA model to simulate the negative ecological and economic impacts of trees on crops, and the benefits of various goods and services derived from trees (soil fertility, shade, fruits, etc.). The value of trees in fields generally decreased with increased rainfall and with increased fertiliser inputs. The model only supports the extensionists’ recommendations that trees should be removed from fields in the case where farmers can use high inorganic fertiliser levels, and for high rainfall regions. However, even under these conditions, 1–2 trees ha⁻¹ may need to be retained for the value of shade. The model further predicts intercropping with trees where fertiliser inputs are low or absent, and where rainfall is low. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The selective conservation of indigenous trees in fields is a traditional agroforestry practice in the smallholder sector of much of Africa (Ingram, 1990). The retained trees are usually intercropped with annual crops (Dancette and Poulain, 1969; Felker, 1978), particularly with maize (Zea mays) (Verinumbe and Okali, 1985; Wilson, 1989; Farrell, 1990). Most farmers value trees more for their traditional roles such as the provision of fruit, fodder, wood, shade, meeting places, and medicines (Milton and Bond, 1986; Wilson, 1989; Grundy et al., 1993) than for their soil ameliorative role (Campbell et al., 1991a). Most trees have higher soil nutrient status under their canopies, but may suppress yields (Chivaura-Mususa and Campbell, 2000).

Eighty percent of trees left in fields are edible fruit-bearing trees (Campbell et al., 1991a). Exotic
fruit trees are often found in fields close to the homestead (Musvoto and Campbell, 1996), whilst indigenous fruit trees are sited in the main fields further away from the homestead. Some of the fruit is consumed in the household and/or by livestock, but some is often sold to raise cash (Musvoto and Campbell, 1996).

Despite the positive influences recorded for some trees on crops in Zimbabwe (Ingram, unpublished), some farmers do perceive trees as having negative effects on crops (e.g. mango trees, Musvoto and Campbell (1996)). Extension workers have encouraged farmers to remove trees from their fields, yet many farmers continue to retain trees in fields. The retention is likely to be due to the market and non-market values of trees rather than soil amelioration effects. Using data on tree-crop interactions from Zimbabwe, we have used the STELLA model to simulate the negative ecological and economic impacts of trees on crops, and the benefits from various goods and services derived from trees. The model is thus used to address the conflict in approach between the agricultural extensionist and the farmer.

As the value of trees in fields in relation to the lost opportunity cost of cropping is probably influenced by rainfall levels and levels of agricultural inputs, these variables are also included in the model. Smallholder farmers generally find inorganic fertilisers too expensive. Application rates are rarely at the recommended levels and only wealthy farmers can afford high levels of fertilisers (Ashworth, 1990). To maintain crop production farmers add various locally-derived soil amendments, such as cattle manure (with 0.5–2% N content), woodland litter (1.4% N), or clay-rich termiaria from termite mounds (high pH, cations, C and P) (Campbell et al., 1998). In a total number of 443 farmers randomly chosen in the Mangwende–Mutoko region of Zimbabwe, irrespective of wealth status, of the nitrogen applied in fields, on average 25 kg N ha\(^{-1}\) per year is from these organic sources and 69 kg N ha\(^{-1}\) per year is from inorganic fertilisers (Campbell et al., 1998).

The aim of the paper is to provide a more nuanced view of the role of trees in fields, rather than focusing solely on tree-crop interactions. By doing so, we aim to investigate whether an optimal number of trees per unit area can be identified, and to examine how such a number may vary depending on socio-economic and bio-physical conditions.

2. Methods and assumptions

STELLA (High Performance System Inc., 1996), a high-level programming language, was used to develop a general simulation model of a hectare of maize intercropped with trees. The following model sectors were developed: (a) rainfall, (b) trees and (c) maize crop. There is only one maize-growing season in a year due to the unimodal rainfall pattern, therefore simulations were run with annual time steps. The net benefits of the trees were calculated, using the applicable prices for inputs and outputs.

One of the main drivers of the model is rainfall, which for the moderate rainfall scenario is generated from 20-year rainfall data from Hwange National Park. Three rainfall scenarios were used as follows: (i) low rainfall region, 300 mm mean rainfall with a standard deviation (S.D.) of 210 mm; (ii) moderate rainfall region, 650 mm with a S.D. of 183 mm; (iii) high rainfall region, 1200 mm with a S.D. of 165 mm.

Tree data calibrations were not species-specific, but generalised from various sources, but calibrations on the crop growth submodel were made using data available from Agritex (1997) and crop-tree studies (Chivaura-Mususa and Campbell, 1998; Chivaura-Mususa et al., 1998). In the tree sector, an average canopy size of 5 m was used and a range of 0–60 trees ha\(^{-1}\) were investigated. This represents 0–47% tree cover in the fields, the range being that recorded by Price and Campbell (1998).

The rainfall and the tree density data feed into the maize crop sector, where maize growth under trees and maize growth away from trees is simulated. In the low (300 mm) and the moderate (650 mm) rainfall regions, larger maize yields were expected under trees than outside trees (Ingram, unpublished), but in the high (1200 mm) rainfall regions larger yields were expected outside the
trees than under trees (Chivaura-Mususa et al., 1998). The calculations of maize yields below and outside trees are averages obtained from two tree species, *Parinari curatellifolia* and *Acacia sieberiana*, where solar radiation was reduced by 80 and 60%, respectively (Chivaura-Mususa et al., 1998).

In this sector, other driving variables, such as the amount of fertiliser inputs from tree litter (Nyathi and Campbell, 1993), from cattle manure (Mugwira, 1984), and from inorganic fertilisers are included. These are introduced as volumes of nitrogen. Three levels of inorganic fertilisers were investigated, 0 kg N ha$^{-1}$, as for poor farmers, 70 kg N ha$^{-1}$ (Campbell et al., 1998), representing wealthy farmers, and 200 kg N ha$^{-1}$, as used by very wealthy farmers. Therefore maize production (grain and stover) was influenced by rainfall, various fertiliser inputs, and the area covered by trees in the field.

While the below-ground maize residues are retained in the arable fields to decompose and probably contribute to soil fertility in subsequent cropping seasons, the maize stover (residue) in the communal areas is often fed to the livestock (cattle), and represents an important value from fields for households. Maize stover is thus included in the calculation of the economic impacts of trees (for instance, if trees reduce stover production, this is captured as an economic loss).

The maize grain prices vary depending on whether subsistence requirements are met (Table 1). The impact of trees on maize grain and stover was calculated based on maize production and costs of labour, fertiliser, utensils, transport or marketing costs as obtained from Agritex (1997). Labour costs were determined by the number of labourers per household, the labour price in a season (Table 1) and the number of days spent in maize production in that season, 45 days being the number of days required to produce 2 t ha$^{-1}$ (Agritex, 1997), and 14 days being the least number of labour days required to prepare land, plant and weed, regardless of crop success or failure.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Farm gate prices (ZS)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize seed</td>
<td>7 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Ammonium nitrate fertiliser</td>
<td>2.49 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Compound D fertiliser</td>
<td>2.125 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Lime</td>
<td>0.23 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Insecticide</td>
<td>7 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Packaging bags</td>
<td>5. 5 bag$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Twine</td>
<td>57 kg$^{-1}$</td>
<td>Agritex 1996/97 current prices (Agritex, 1997)</td>
</tr>
<tr>
<td>Agricultural labour</td>
<td>12 day$^{-1}$ per person$^{-1}$ (6 hours day$^{-1}$)</td>
<td>Current Grain Marketing Board prices for grain, with the high value being a local exchange rate for the dry season. Stored maize from previous seasons diminish in value probably due to diseases or pests or poor storage conditions 10% of grain value in local exchange</td>
</tr>
<tr>
<td>Maize grain</td>
<td>1.2 kg$^{-1}$, but rising in years when subsistence levels are not achieved to a maximum of 2.5 kg$^{-1}$ when no grain is harvested. Reserved stores of maize can be sold locally at 67.5% of maize price</td>
<td></td>
</tr>
<tr>
<td>Maize stover</td>
<td>0.2 kg$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>Firewood and labour</td>
<td>0.15 kg$^{-1}$ (production costs are 10% of total firewood value)</td>
<td>Campbell et al. (1995)</td>
</tr>
<tr>
<td>Fruit and labour</td>
<td>3–6 tree$^{-1}$ (production costs are 10% of total fruit value)</td>
<td>Campbell et al. (1995)</td>
</tr>
<tr>
<td>Organic matter (manure or tree litter)</td>
<td>0.04 kg$^{-1}$, 30 per scotchcart (a cart is assumed to be equivalent to 750 kg capacity)</td>
<td></td>
</tr>
<tr>
<td>Costs of baby sitting</td>
<td>6 day$^{-1}$</td>
<td>50% of 1996/97 legal urban labour rates for baby sitting</td>
</tr>
</tbody>
</table>
Fruits from trees were valued as supplements to the subsistence diet in the household, with labour costs for fruit collection included (Table 1). It was assumed that 50% of fruit produced by trees was consumed by the household and labour costs for fruit collection were 10% of the gross value (labour costs for trees in woodlands far from homesteads can rise to 50% — Campbell et al. (1995)). In addition, fruit had a diminishing marginal value for the farmer, falling from Z$6.00 per tree for 1 tree ha$^{-1}$ to Z$3.00 tree$^{-1}$ for 60 trees ha$^{-1}$. Trees produce wood for fuel, which was valued at the current farm gate price for firewood (Table 1). The trees also produce litter and, through decomposition, tree litter increases organic matter and increases fertility status in soils. Litter was included in the model as a positive value of trees in fields, and was valued in terms of organic matter content at prices equivalent to manure (Table 1). Wood for craft, honey and medicinal values of trees in arable fields were considered as generally insignificant value, less than Z$0.01 ha$^{-1}$ (Campbell et al., 1991b). Existence or passive values and option (future use) values were not considered because they are values that were difficult to give a monetary value.

Trees in fields create shade which has costs in terms of reduced crop production, and benefits in terms of places to rest and eat, and places to leave babies whilst working in the field. The value of shade was based on the number of rest periods required per working day, in which the household members may rest and feed under trees, instead of travelling back to the homestead. The value was thus calculated as the lost time that would be incurred if trees were not available and the persons had to return to their homestead (Table 1). Shade trees also allow nursing mothers to place their babies under trees and watch over them instead of employing someone to baby sit, thus the value of a tree was calculated as the babysitting cost that would be incurred if there were no trees. Optional no-cost babysitting, e.g. by grandmothers, would nullify this value, but there was no data available for calibration. For more than one tree per hectare there was no marginal increase in shade value as it was assumed that one tree per ha was sufficient to meet the needs.

All prices are for 1996/1997 and are in Zimbabwe dollars, which at the time were Z$10.00 = US$1.00.

3. Modelling approach

To investigate the value of trees in arable areas a number of simulations were run, with the simulations differing by rainfall level, the number of trees in the field or the level of fertiliser inputs. Simulations were run for 50 years for each combination of conditions, and the annual mean value of trees per hectare of field was calculated; these values being the differences between the total costs and total benefits. The economic impact of trees on maize production was incorporated in this value by calculating the gain or loss of production as a result of trees being present. The number of trees that gave the highest economic value could thus be determined for each combination of mean rainfall and fertiliser input level.

4. Results

Annual means on 50-year simulations show that tree value generally decreases with increasing rainfall and with increasing fertiliser input, apart from at low tree densities where values are similar across different rainfall and fertiliser regimes (Fig. 1). For the low rainfall region the value of trees in fields increases with increasing tree density, even up to 60 trees ha$^{-1}$, an equivalent of 47% tree cover in fields (Fig. 1a).

In the moderate (650 mm) and the high (1200 mm) rainfall regions, the number of trees that gives the highest economic benefit to farmers was greatly influenced by wealth status of farmers, as represented by fertiliser input levels (Fig. 1b and c). The value of trees increases as tree density increases for the poor farmers, who do not apply any inorganic fertilisers, irrespective of the amount of rainfall received. For the wealthy farmers who can afford to apply 70 kg inorganic N ha$^{-1}$, tree densities ranging from 5 to 30 trees ha$^{-1}$ returned the greatest benefit to the farmer in moderate and high rainfall regions. This was un-
5. Discussion and conclusions

The results imply that the richer the farmer the lower is the value of trees in fields. For very wealthy farmers who have the resources to ensure high crop yields, the negative impacts of trees (mainly reduced crop yield) outweigh the benefits of trees (particularly shade and fruit). The recommendation by the extension service to remove all trees from fields is understandable in this context of high inorganic fertiliser use (another recommendation from the extension service), though even at these fertiliser regimes farmers are still expected to retain one or two trees per hectare in their arable fields for shade (Campbell et al., 1991a).

However, amounts of inorganic fertilisers applied by farmers are much less than those recommended by the extension service (Cooper and Fenner, 1981), as recorded in the Mangwende–Mutoko, Chivi, Chiwundura and Gutu regions (Campbell et al., 1998; Muza, 1995). Farmers achieve their target yields without high inorganic fertiliser application rates due to management strategies such as combining inorganic and organic fertilisers (Campbell et al., 1998). As most communal farmers cannot afford large quantities of inorganic fertilisers, trees become more valuable. This occurs because the loss of grain production due to canopy shading is not as great as in circumstances where high grain production is possible. Hence, farmers are more likely to retain trees in fields in these circumstances. At Domboshawa Training Centre as many as 10 and 7 trees ha\(^{-1}\) of \textit{A. sieberiana} and \textit{P. curatellifolia} individuals, respectively, were retained (Chivaura-Mususa et al., 1998) and in Mangwende Communal Lands 11 mango (\textit{Mangifera indica}) trees ha\(^{-1}\) were kept in fields (Musvoto and Campbell, 1996). In the drier Mutoko area as many as 22 trees ha\(^{-1}\) are retained (Price and Campbell, 1998). All these numbers are within the range of 5–30 trees ha\(^{-1}\) simulated in the model as an optimum number of trees in high and moderate rainfall regions, given low levels of inorganic fertiliser inputs.
The model predicts intercropping with trees where fertiliser inputs were lower, and where rainfall was lower. Conflicts between the farmer and the extensionists need not exist as long as extensionists consider the rainfall regime and wealth status of the farmers prior to making recommendations about tree removal from fields.

In general, this model provides valuable insights into the economics of tree retention and removal. However, the model needs to be further developed. More ecological aspects of tree–crop interaction could be incorporated rather than relying simply on the relationship between tree crowns and maize yield. The dynamics within the household also need to be captured (e.g. the values of the trees for fruits may accrue largely to women, while the value of maize grain may accrue largely to men). The role of trees in potentially guarding against risks needs to be considered (e.g. fruit value in a drought year has been underestimated in the current model). Although various values of trees were incorporated in the model, it was difficult to put monetary values on a number of tree services, e.g. social values such as performance of rain ceremonies under trees. This model also does not simulate the impact of trees for different tree species or for crops other than maize, and the model needs to be extended to cover trees in pastures.

References