Modeling cropping strategies to improve human nutrition in Uganda

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Received 28 February 2000; received in revised form 5 September 2000; accepted 12 September 2000

Abstract

This paper contrasts two Ugandan cropping systems, a banana-based (Musa AAA) and a grain-based (Zea mays and Sorghum bicolor), and focuses on the potential of each to provide food in sufficient quantity to meet household nutritional requirements. The objectives of this study were to estimate the amount of energy, protein, vitamin A, Ca, Fe and Zn furnished by these two systems; and to model cropping strategies capable of improving nutritional output given the same land area and location. Results show that both systems currently fail to satisfy a range of nutritional needs with Zn and Ca deficits being the most extreme. Modifications in cropping strategies explored through modeling showed that improved nutrition in both systems was possible given the same resource base. Improved nutrition in the banana-cropping system requires major changes in the allocation of land: e.g. a two-thirds reduction in the proportion of land devoted to banana. Adequate nutrition given the same resource base would require the incorporation of several species (e.g. Amaranthus lividus and Glycine max), which though present are uncommon. Though we suggest changes in extant cropping systems, this paper acknowledges that such changes would occur in the context of practices embedded in cultural norms.

Keywords: Modeling; Human nutrition; Land allocation; Cropping systems
1. Introduction

Food crises in developing countries have traditionally been regarded as food shortages. Consequently, our attention has focused on improving access to food and supplementing food supplies by providing emergency relief. However, many developing countries may suffer from a different type of food crisis: the chronic incapacity of traditional diets to provide adequate amounts of essential nutrients. In contrast to the conventional view of food crises as a function of insufficient caloric intake, this view suggests that a successful food strategy must recognize the importance to human nutrition of both the quantity and the quality of food available to a population (Van Hoek, 1988).

Altering crop selection, increasing the land area allocated to crops rich in requisite nutrients, or introducing dietary supplements can modify the diets of rural farm families. Recent work has also pointed to the potential for increasing micronutrient density in foods through plant breeding (Bouis, 1999) and through fertilizer application (Rengel et al., 1999). However, plant breeding has yet to effect nutrient enhancement in the major staple crops of developing countries; and both organic and inorganic inputs are often beyond the financial means of small landholders. Hence, this paper focuses on the potential for improving nutrition through, first, increasing the land area allocated to nutrient-rich crops and, second, altering crop selection to include crops rich in requisite nutrients.

Wholesale changes in a system may be difficult to promote because cropping strategies are embedded in cultural norms and reflect the availability of material and physical inputs and the farmers’ perceptions of risk. Consequently, this paper analyzes the food produced by two common Uganda cropping systems (banana-based, *Musa AAA*; and grain-based, *Zea mays* and *Sorghum bicolor*) and suggests minor alterations, such as area allotted per crop, to improve nutrition within these systems. Alterations in crop selections that could potentially improve land use and in some cases decrease the amount of land area needed to meet nutritional requirements for energy, protein, vitamin A, calcium, iron and zinc are also investigated through simulation modeling.

Our objectives in this study were:

1. to estimate crop yield production and the energy, protein, vitamin A, calcium, iron and zinc furnished by the crops; and
2. to model cropping strategies capable of improving nutritional output given the same land area and location.

2. Materials and methods

2.1. Site description

The banana- and grain-based cropping systems selected for this study represent two of Uganda’s most important systems, currently as well as historically (Mukasa
and Thomas, 1970). Banana-based systems predominate in the central, southern and eastern regions of the country, while grain-based systems predominate in the northern and western regions. For this study, a grain-based system was represented by farms in southwestern Uganda in Nyarurambi parish, Kabale District (1.25°S 30°E), while the banana-based system was represented by farms in southern Uganda in Nakatete parish, Masaka District (0.33°S 31.7°E). Kabale (grain-based) and Masaka (banana-based) Districts are populated by 228 and 79 people km$^{-2}$, respectively (Rwabwoogo, 1998). Throughout this paper, we refer to the study areas by the system they represent.

Daily maximum and minimum air temperatures in the Masaka study area (1300 m asl) average 26 and 14°C, respectively. Rainfall in Masaka is bimodally distributed and averages approximately 1100 mm annually. Soils in the Masaka study area (0–2% slope) are derived from gneisses and granites and are predominantly sandy clay loams with pH > 6 (Radwanski, 1960). Air temperatures are cooler in the Kabale study area (1950–2175 m asl) with daily maximum and minimum air temperatures averaging 23 and 10°C, respectively.

Soils in the Kabale study area (18–36% slopes) are derived from metamorphic rock (phyllite) and are characterized by a clay loam texture with pH ranging from 4.5 to 6.5 (Harrop, 1962). Soils in the study area are classified as Haplohumults, Kandiudults or Sombrihumults (USDA taxonomy; Yost and Eswaran, 1990). Rainfall in Kabale is also bimodally distributed and averages approximately 1000 mm annually.

2.2. Survey protocol

During 1998, 31 farms were surveyed in each parish. Within a parish, the sole criterion for farm selection was cropped area — all the selected farms had 0.5–1 ha of cultivated land. This area is representative of the average land under cultivation on farms in both districts.

Since annual rainfall is bimodally distributed, both districts have two cropping seasons per year. Food crop species, area allotted to each crop and plant density were recorded at each farm for the season during which the survey was conducted, and the same data was gathered for the previous cropping season through querying household members.

Calculating the area allotted to each crop species was complicated by the practice of intercropping, which is common in both farming systems, though it is more widely practiced in Masaka than in Kabale. In calculating crop area, the dominant crop was assumed to occupy the entire area if the minor crops were sparsely populated. In this case, the minor crop(s) was assigned an area based on optimal plant populations. For example, if the optimal sole crop population is 8 plants m$^{-2}$ and the crop was grown at a density of 1 plant m$^{-2}$, then the assigned area = actual number of plants/optimal plant density. (This algorithm results in a slight overestimation of cultivated land.) If no single crop was dominant, all crops were assigned a fraction of the total areas occupied based on their preponderance within the multi-cropped area.
The women associated with the farms were asked to describe whom they cooked for and how and when the number varied in order to assess the number, age and sex of people fed by the produce of each farm. This ‘cooking-pot methodology’ was chosen because it allowed for the inclusion of consumers of farm produce who were not household members (laborers, neighbors and relatives), but who were fed on-farm; and of consumers of farm produce who were fed off-farm. Off-farm consumption results when one or more wives is domiciled away from the farm but has access to crops produced (usually through her labor) on the farm.

The consumption units (CU) for each farm were obtained by summing the consumption units for each individual fed by the farm. The assignment of individual consumption units is based on FAO (1990) designations (Table 1).

2.3. Model parameters

Data for the model consisted of experimentally determined values and parameters derived from historical and survey data. Experimental data included land area allotted per crop and the edible fraction of harvested yield. Land area per crop was assessed on every farm as reported in the survey protocol section above. Edible fractions were experimentally determined by weighing at least 10 samples of the food crops encountered in the study areas.

Yield was based on surveys done in each district by the Uganda Ministry of Agriculture, Animal Industries and Fisheries (1992). These data most likely overestimate crop yields and thus the human nutrient outputs simulated in this study are probably biased upwards. Sole crop production data were modified to reflect yield reductions noted in intercropped systems (Wortmann et al., 1992). In this paper we assume that farmers aim first to feed household members and then to use whatever surplus remains for barter or sale and that the quality of the purchased foods does not exceed that of the foodstuffs that are sold.

Nutrient values (Table 2) and moisture contents of food items are based on recommended daily nutritional allowances (RDAs) as contained in the USDA standard nutrient database (US Department of Agriculture, 1999). The amount of nutrients produced on each farm was calculated on a seasonal basis from the edible fraction of the estimated yield data. The seasonal amounts were summed and divided by the number of CU on a farm to obtain the annual farm nutritional output per CU.

### Table 1
Consumption units based on age and sex of individual (FAO, 1990)

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>1–6</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>7–13</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>14–19</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>20–59</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>&gt; 59</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Table 2
Yield and nutrient composition of some major food crops in banana- and grain-based systems in Uganda

<table>
<thead>
<tr>
<th>Crop species</th>
<th>Harvest (fresh; kg ha(^{-1}) year(^{-1}))</th>
<th>Edible yield (fresh; kg ha(^{-1}) year(^{-1}))</th>
<th>Edible yield (dry; kg ha(^{-1}) year(^{-1}))</th>
<th>Energy (MJ per kg dry edible yield)</th>
<th>Protein (g per kg dry edible yield)</th>
<th>Vit A (µg RE per kg dry edible yield)</th>
<th>Zn (mg per kg dry edible yield)</th>
<th>Fe (mg per kg dry edible yield)</th>
<th>Ca (mg per kg dry edible yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musa AAA Banana</td>
<td>12 600</td>
<td>6048</td>
<td>1554</td>
<td>15.0</td>
<td>40</td>
<td>311</td>
<td>6</td>
<td>12</td>
<td>233</td>
</tr>
<tr>
<td>Phaseolus vulgaris Bean</td>
<td>1600</td>
<td>1600</td>
<td>1430</td>
<td>16.0</td>
<td>243</td>
<td>0</td>
<td>29</td>
<td>66</td>
<td>1358</td>
</tr>
<tr>
<td>Brassica oleracea Cabbage</td>
<td>8960</td>
<td>7885</td>
<td>615</td>
<td>13.5</td>
<td>185</td>
<td>1667</td>
<td>23</td>
<td>76</td>
<td>6026</td>
</tr>
<tr>
<td>Manihot esculenta Cassava</td>
<td>11 500</td>
<td>9200</td>
<td>2898</td>
<td>16.6</td>
<td>34</td>
<td>50</td>
<td>8</td>
<td>7</td>
<td>397</td>
</tr>
<tr>
<td>Pisum sativum Green pea</td>
<td>960</td>
<td>960</td>
<td>203</td>
<td>16.1</td>
<td>257</td>
<td>3033</td>
<td>59</td>
<td>70</td>
<td>1185</td>
</tr>
<tr>
<td>Amaranthus lividus Greens</td>
<td>8800</td>
<td>7040</td>
<td>584</td>
<td>13.1</td>
<td>296</td>
<td>35181</td>
<td>108</td>
<td>280</td>
<td>25904</td>
</tr>
<tr>
<td>Arachis hypogea Groundnut</td>
<td>3280</td>
<td>3280</td>
<td>3067</td>
<td>25.4</td>
<td>276</td>
<td>0</td>
<td>35</td>
<td>49</td>
<td>984</td>
</tr>
<tr>
<td>Solanum tuberosum Irish potato</td>
<td>8000</td>
<td>6800</td>
<td>1564</td>
<td>15.8</td>
<td>99</td>
<td>0</td>
<td>19</td>
<td>36</td>
<td>333</td>
</tr>
<tr>
<td>Zea mays Maize, white</td>
<td>3100</td>
<td>3100</td>
<td>2781</td>
<td>17.1</td>
<td>105</td>
<td>0</td>
<td>25</td>
<td>30</td>
<td>78</td>
</tr>
<tr>
<td>Mangifera indica Mango</td>
<td>12 000</td>
<td>8400</td>
<td>1537</td>
<td>14.9</td>
<td>28</td>
<td>21257</td>
<td>2</td>
<td>7</td>
<td>546</td>
</tr>
<tr>
<td>Ipomea batatas Sweet potato, white</td>
<td>16 000</td>
<td>13 600</td>
<td>3699</td>
<td>16.1</td>
<td>61</td>
<td>1287</td>
<td>10</td>
<td>22</td>
<td>809</td>
</tr>
<tr>
<td>Sorghum bicolor Sorghum</td>
<td>2000</td>
<td>2000</td>
<td>1816</td>
<td>15.6</td>
<td>124</td>
<td>0</td>
<td>0</td>
<td>48</td>
<td>308</td>
</tr>
<tr>
<td>Glycine max Soybean</td>
<td>3380</td>
<td>3380</td>
<td>3093</td>
<td>19.0</td>
<td>399</td>
<td>22</td>
<td>53</td>
<td>172</td>
<td>3027</td>
</tr>
</tbody>
</table>

\(^a\) Crop yields presented are means for Masaka District, Uganda, Kabale District yields differ for some crops.
To investigate alternative cropping strategies we used an optimization tool, a common feature in most spreadsheet programs. These tools optimize a given function and have provisions for placing constraints on parameters within the function. We used an optimization model that minimized the land area required to produce targeted nutrient requirements (energy, protein, vitamin A, zinc, calcium and iron) given the selected crops. The restrictions on protein, vitamin A, zinc, calcium and iron were set at “equal to or more than” the specified level, while energy was set at “equal to” the specified level.

In model simulations, constraints were also placed on foods such that daily intake for a food was limited to a quantity between zero and an upper limit. These upper limits took into account cultural as well as dietary norms. For example, whereas a lettuce-tomato salad followed by pasta with a tomato-based sauce might be an acceptable evening meal in some parts of the world, Ugandans seldom consume tomatoes in quantities greater than 0.15 kg fresh mass per CU per day. Likewise, an upper limit of 0.15 kg fresh mass was placed on *Amaranthus* spp., even though the daily requirements for Fe and Ca can be met more easily if larger quantities of greens are consumed.

### 3. Results

#### 3.1. Banana-based system

Land area devoted to food crops (1450 m² CU⁻¹) within the banana-based system averaged 87% (Table 3) of the total cropped area. There was no relationship between cropped area and number of CU farm⁻¹. If all adults aged 20–59 are considered available for farm labor, 2.5 adults farm 1 ha and one person’s labor feeds 3.1 people (2.4 CU). (This represents an optimum labor arrangement; in reality, children are often required to work on farms, in addition to or even in place of attending school.) There was no significant relationship between the number of crop species present on a farm and that farm’s output of any of the assessed nutritional parameters. Similarly, there was no significant relationship between the number of crop species present on a farm and that farm’s output of any of the assessed nutritional parameters. Similarly, there was no significant relationship between the number of crop species

<table>
<thead>
<tr>
<th>Description</th>
<th>Banana</th>
<th>Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people fed (median/mean)</td>
<td>7.0/6.6</td>
<td>8.0/7.9</td>
</tr>
<tr>
<td>Consumption units (median/mean)</td>
<td>4.9/5.0</td>
<td>5.9/6.2</td>
</tr>
<tr>
<td>Mean area (ha year⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food crops</td>
<td>0.723</td>
<td>0.677</td>
</tr>
<tr>
<td>Cash crops</td>
<td>0.106</td>
<td>0.015</td>
</tr>
<tr>
<td>Total area</td>
<td>0.829</td>
<td>0.692</td>
</tr>
</tbody>
</table>
present on a farm and the number of nutritional standards met by that farm’s output. An average of 13 food crop species (including fruit tree species) was found per farm with a total of 25 crops represented among all of the farms. Banana occupied most of the available cropping area (Fig. 1a). Indeed, 10 times as much land was devoted to banana as to either of the two other important staples, sweet potato (Ipomea batata) and bean (Phaseolus vulgaris).

As food crop area increased, nutrient production increased, but the increase, using a linear expression, in protein was not as strongly correlated with the increase in cropped land as was the increase in energy (Fig. 2a).

Livestock appeared to directly contribute little, if anything, to household nutrient intake. Although livestock were present on 42% of the 31 farms, the numbers were low, e.g. one or two chickens, or a goat awaiting holiday slaughter; and all respondents stated that eggs were not eaten by household members, but instead were sold or traded.

All of the households, whether energy-sufficient or not, stated that farm production was sufficient to feed the household members, and 90% of the households stated that they had a small amount of surplus food to sell. Three of the respondents stated that the proceeds from their surplus were used for other staples, such as maize flour and rice (Oryza sativa), whereas the remainder indicated that the money was used for school fees and emergencies, such as medical problems.

The most glaring nutritional deficits in the banana-based system were the lack of calcium and zinc, but iron and protein were also deficient (Table 4). Protein ($r^2 = 0.71$), zinc ($r^2 = 0.73$), iron ($r^2 = 0.79$) and calcium ($r^2 = 0.89$) increased as energy increased, but Vitamin A was poorly correlated with energy ($r^2 = 0.19$).

### 3.2. Grain-based system

Land area within the grain-based system devoted to food crops (1090 m² CU⁻¹) was 98% of the total cropped area (Table 3). As in the banana-based system, there was no significant relationship between cropped area and the number of CU farm⁻¹. There were more CU farm⁻¹ (and per ha) in the grain-based system. While the higher number of consumption units in the grain-based system translated into a need for more food, it also meant that there was more labor available on farms in the grain-based cropping system.

Vitamin A increased as the number of species increased ($P < 0.05$), but as in the banana-based system, there was no relationship between the number of crops on a farm and the number of nutritional standards met by the farm. The mean number of food crop species (8.6) on a farm was less than in the banana-based system (13), but the number of species represented in each study area was similar.

Compared with the banana-based farms, the grain-based farms were more effective at producing protein, iron, and zinc and less effective at producing energy and Vitamin A (Table 4). This contrast reflects the strengths and weaknesses of nutrient provision of the major staples in each system (banana vs. grains/bean).

As in the banana-based system, nutrient production in the grain-base system increased as food crop area increased. However, the increases in protein and energy
Fig. 1. Proportion of land in the banana-based system allocated to various food crops (a) currently and (b) when a dietary constraint (0.5 kg fresh mass per consumption unit per day) limits banana consumption and thus land area in banana.
were more strongly correlated with an increase in crop area than was the case in the banana system (Fig. 2). As energy increased, so did protein ($r^2=0.79$), zinc ($r^2=0.81$), iron ($r^2=0.86$), calcium ($r^2=0.87$) and Vitamin A ($r^2=0.58$).

Livestock was present on three (<10%) of the farms. Two of these three farms had a few cattle, while the other had a pig.

Fig. 2. Energy and protein by land area in food crops for (a) banana-based and (b) grain-based systems.
Although 74% of the farms in Kabale stated that they produced enough food, less than 20% of this group reported that they had surplus available for sale. There was no difference in nutrient availability between the farms that regarded themselves as self-sufficient in food production and those that did not. Over 25% of the households reported that they sometimes sold crop produce, even though they stated there was insufficient food to meet the needs of the household. Respondents stated that the income from crops that were sold was used primarily to pay taxes or meet other emergency needs and occasionally to purchase staples and other commodities, such as tea and sugar.

### 3.3. Modeling results

Ideally, crop selection would be such that an adequate diet could be attained without major changes in the cropping system. Since the banana-based farms average 1450 m² CU⁻¹ in food crops (Table 3), the initial simulation was constrained to an equivalent cropped area and major food and fruit tree species currently found within the system. In other words, we held constant both the amount of land currently available per consumption unit and the food crops currently found in the system.

In this scenario nutritional standards were met when land area and species were held constant, but banana declined to 3% of the land area cultivated with food crops. When species were held constant and land area was minimized, this scenario resulted in the exclusion of banana by the model as an effective contributor to nutrient provision. In this minimization scenario, nutritional standards were met with 1150 m² CU⁻¹ (21% less land than that currently cultivated with food crops). Zinc and calcium were the limiting nutrients.

Since removing banana from the diet is culturally untenable, we ran a simulation that forced banana’s inclusion. This inclusion was accomplished by establishing a constraint setting daily banana consumption to 0.45 kg fresh mass CU⁻¹. Forcing consumption to equal this amount kept banana in the system (21% of cropped area), but resulted in adequate nutrition (Fig. 3) and decreased the land requirement by approximately 9% (Fig. 1b).

### Table 4

Farms producing less than the stated recommended daily allowance (RDA) for a particular mineral or nutrient per consumption unit in a banana-based system (Masaka District) and a grain-based system (Kabale District) in Uganda

<table>
<thead>
<tr>
<th>RDA</th>
<th>Banana-based (%)</th>
<th>Grain-based (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MJ)</td>
<td>10.46</td>
<td>39</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>52</td>
<td>55</td>
</tr>
<tr>
<td>Vitamin A (g RE)</td>
<td>1000</td>
<td>64</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>800</td>
<td>97</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Zinc (mg)</td>
<td>15</td>
<td>94</td>
</tr>
</tbody>
</table>
The cropped area in grain-based farms averaged 1090 m² CU⁻¹, with the greatest percentage of crop area planted with bean and grains (Fig. 4a). Initial simulations indicated that given the same land area and the same food crops, the nutritional requirements for Zn and Ca could not be met. The standards were met when species (*Amaranthus lividus* and *Glycine max*) present on some farms, though not all, were included in the simulation (Fig. 5). The simulation that included these crops did not reduce the cropped area (Fig. 4b).

4. Discussion

4.1. Human nutrition

Van Hoek (1988) pointed out that any measure of food sufficiency should take into account the quality, as well as the quantity, of food available to consumers. As currently configured, both the banana- and grain-based cropping systems yield substandard diets for the farm households within them. These deficiencies are particularly troubling considering that this study likely overestimates nutrient availability both in situ and in model projections. In Uganda, malnutrition of one sort or another is endemic. For example, 36% of all children under 36 months of age and 10% of Ugandan mothers (with children between ages 3 to 48 months) suffered from chronic undernutrition (Child Health and Development Center, 1995).

In this study, the dietary requirements that are most difficult to meet in both cropping systems, and that consequently force the required cropland area upward,
are calcium and zinc. Disparities in the literature concerning the nutrient values of some crops found more often in developing countries than in developed ones underscore a need for research on the nutrient composition of foods not commonly analyzed. For example, cassava — a high-calcium crop — is a common staple in Uganda; the database used in this study assigns it a value lower than some other...
values reported in the literature. Using a higher value for cassava would dramatically decrease the land area required and perhaps alter the mixture of crops grown. This disparity in nutrient values points to the critical importance of compiling reliable data for agricultural planning and the consequent need to promote more and better research on food quality in developing countries.

4.2. Cropping systems

The alternative strategies investigated here for meeting the RDA in the banana cropping system require major changes in the allocation of land to specific crops: a 69% decrease in the proportion of land devoted to banana; a 100% increase in land allotted to maize; and a 600% increase in the proportion allocated to groundnut. These changes will become increasingly urgent should land pressure increase much beyond the current population density in this region of 79 people km\(^{-2}\).

Adequate nutrition can be achieved within the grain-based cropping system only with the inclusion of crops not commonly included in the current system. For example, greens and soybean (crops rich in Zn and Ca) are not prevalent on most farms, but their presence dramatically increases the quality of the diet.

The question remains, however, whether these changes are viable. That is, are there agronomic, socio-economic and/or cultural constraints that might impede the optimization of current cropping systems?

There is evidence that changes in crop selection have some precedent in Uganda. In 1964, only 68% of Masaka landholders planted bean and less than 37% planted sweet potato (Uganda Ministry Agriculture and Cooperatives, 1966). Today, almost all (94%) of the landholders cultivate bean and 74% cultivate sweet potato. In 1968,
improved bean cultivars were introduced in the area by the Uganda Bean Program, but it is unclear how much impact they have had on farmers’ choices (Sengooba, 1997). It is noteworthy that the Bean Program was initiated in response to a 1950s WHO survey that found extensive protein malnutrition in the banana-growing regions of Uganda (Rubaihayo et al., 1981).

The presence or absence of agronomic and other production-related constraints will affect the extent to which cropping systems can be transformed. Cultural valorization of certain foods over others and labor availability may also play substantive roles in the choice of crops. Labor may be central to decisions that farmers make regarding cropland allocation. For example, perennial crops, such as cassava and banana, are more common in Masaka than in Kabale. The survey data suggest that labor shortages are more severe in Masaka than in Kabale (an adult in Masaka must work 37% more land than their counterpart in Kabale). In both regions, successful minimization scenarios were dependent on annual crops, which require more labor than do perennial systems. Is the labor available?

Labor availability in the years to come will be determined by Uganda’s shifting demographics. In large part due to AIDS, the proportion of the population that is comprised of adults old enough but not too old to work continues to shrink, increasing the labor burden on both children (48% of the population is under age 15) and the elderly — particularly elderly women (Way and Staneki, 1994). In this context, any dramatic shift upward in labor requirements is unlikely to be tenable.

Land availability may also inhibit changes in cropping systems. Is there sufficient land available, particularly in the grain-based system, to implement the proposed changes? Currently, population density is almost three times higher in Kabale than in Masaka. Model projections predict that a prudent selection of crops in Kabale could support an increase in population density of only about one more consumption unit per cropped hectare.

4.3. Implications for policy

Policy may play a role in farmers’ willingness to embrace a transition from low-management (low input) systems to intensively managed (high input) systems. Increasing the use of inputs such as fertilizer and pesticide may require support in the form of changes to government policy as well as changes in the training and activities of government extension workers.

The labor issues highlighted by this study carry policy implications as well. The projected decline in the size and age of Uganda’s labor force due to the HIV/AIDS pandemic, combined with the fact that over 55% of Ugandan households do not even meet 80% of the daily recommended energy intake (Uganda Ministry of Finance and Econ. Planning, 1996), brings the question of food security to the forefront of policy discussions involving agricultural technologies. Food security, defined as access to the requisite quantity and quality of food to promote physical well-being, may depend on the successful adoption of technologies that decrease labor inputs and increase other inputs such as fertilizers and pesticides. Policies that promote the appropriate use of such inputs will thus become increasingly important.
5. Conclusions

Current cropping strategies in both the banana- and grain-based systems result in diets that do not meet the requirements for energy, protein and minerals. Calcium and zinc were limiting in both systems. Nutrient deficiencies in the banana-based system appear to be rooted in land allocation decisions rather than in land shortage, whereas in the grain-based system the deficiencies result from a preponderance of crops low in minerals.

This study’s findings underscore the usefulness of spreadsheet optimization tools to evaluate the potential of cropping system modifications for improving nutritional output — an approach that could fruitfully be adopted for future research. Other directions for future research indicated by this study’s findings include questions concerning agronomic, cultural and labor-related constraints on the malleability of current cropping systems; factors other than cropping systems that influence human nutrition; and the types of policies best suited to addressing nutritional problems through agricultural practices.

In conclusion, this study begs a closer look at population thresholds and land allocation in relation to nutrient availability. But perhaps more important, it points to the demand for an intensive examination of the relationships between labor and cropping systems in the face of a shrinking labor pool caused by the HIV/AIDS pandemic.

Acknowledgements

We are grateful to the Rockefeller Foundation, USA, for the financial support provided for this research; to Dr. Elizabeth Robinson for helpful comments on the project proposal; to Dr. Cary Farley for logistical support; and to the reviewers.

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