Long-Run *Striga* Control by Subsistence Farmers in Mali

By Jeffrey D. Mullen, Demba Kebe, Daniel B. Taylor, and Makan Fofana
Section 1: Introduction

The parasitic weeds belonging to the genus *Striga* are among the world’s most tenacious, prolific and destructive agricultural pests. *Striga* species have taken root throughout the continents of Africa and Asia, imparting extensive damage to staple cereal crops. Mboob estimates that annual cereal yields in Africa are reduced by 40% due to *Striga*. The losses, however, are not distributed evenly across the continent. The weeds’ affinity for low-fertility soils and low rainfall means that those farming the most marginal lands are most severely affected. Lagoke et al. (1991) put the matter more dramatically in stating, “parasitic weeds threaten the lives of more than 100 million people in Africa” (p. 3).

On the southern fringe of the Sahara Desert, with unimodal, average annual rainfall between 400 and 800 mm, the agroclimatology of Mali’s Sahelian region is particularly suited to *Striga*. In 1986, Konate found Malian fields of millet and sorghum that suffered yield losses of up to 100% due to *Striga* infestations. In 1995, farmers in Mali’s Mourdiah and Sirakorola zones ranked *Striga* as their number one pest problem (IPM-CRSP/Mali, 1995). The implications of *Striga*’s presence in Mali are reflected in the decline of per capita food production (-0.9% from 1979 to 1992), the increase in cereal imports (up 10,000 tons from 1980-1992), and the increase in cereal food aid (up 14,000 tons from 1979/1980-1991/1992) (World Bank, 1994). And yet, despite the proliferation of the pest and the damage it causes, Malian farmers have not adopted *Striga* control practices to any appreciable degree (Debrah, 1994).

There are a number of factors that may serve as barriers to the adoption of *Striga* control practices. First, the labor and financial demands of many practices may preclude their adoption by subsistence farmers. Second, farmers often lack information regarding new *Striga* control measures. This “information gap” may take many forms: (1) farmers may not know how to apply a control measure properly; (2) expected returns to practices may not be known, so farmers cannot make appropriate adoption decisions; or (3) farmers simply may not know the practice exists. A third factor that may impede the adoption of *Striga* control practices is the inherent discount rate of subsistence farmers. The fact that *Striga* causes damage before it emerges, i.e., before most practices can be applied, means that much of the return to investment in *Striga* control this season will not be realized until some season in the future. The fourth issue has to do with the dispersion of *Striga* seeds. The mobility of *Striga* seeds poses a very real threat of re-infestation. The marginal value product of a practice must, therefore, be discounted not only by the producer’s rate of
time preference, but also by the probability of re-infestation. To be attractive to farmers, practices must be productive enough to overcome both of these sources of discounting.

Seed dispersion also introduces a social element into the individual producer’s adoption decision. Because seeds can be transported across fields, the threat of re-infestation comes not only from one’s own fields, but from the fields of one’s neighbors as well. In other words, there is a “seed externality” associated with failure to control Striga. As a result, an individual’s long-run expected return to Striga control practices is contingent on the degree to which their neighbors manage to control the pest. One’s adoption decision, then, may be influenced by their expectations regarding their neighbors’ control efforts.

This paper develops a dynamic programming model capable of identifying: (1) affordable, effective Striga control practices consistent with the resource constraints of subsistence farmers; and (2) barriers to the adoption of those practices. The model is comprised of two components: a biological component modeling Striga population dynamics, and an economic component representing the production opportunity set, resource constraints, and price parameters farmers face. The model is applied to the Mourdiah zone of northwest Mali.

In the next section, the biological component of the model is developed. Section 3 presents the economic component of the model, including a brief discussion of the socio-economic context of the study area. In Section 4 the results of the model are discussed, including the optimal set of practices identified by the model and the relevance of each potential barrier to the adoption of those practices.

Section 2: Modeling Striga Population Dynamics

Striga species are obligate parasites that attack the roots of their host, draining the host of nutrients and causing a variety of debilitating symptoms. The parasitization occurs subterraneanly, prior to the weed’s emergence. In fact, the host crop may be severely damaged, or even killed, before any Striga emerge from the soil (Parker and Riches, 1993). This ability to damage crops before revealing itself to farmers has earned Striga its more common name, “witchweed.”

The biological component is based on the models of Striga population dynamics developed by Kunisch et al. (1991), Smith, Holt, and Webb (SH&W) (1993), and Smith and Webb (S&W) (1996). The Striga lifecycle is divided into eight distinct stages: (i) seed stimulation by host root exudate or synthetic stimulant; (ii) germination; (iii) attachment to host roots; (iv) emergence; (v) maturity to reproductive age;
(vi) reproduction of new seeds; (vii) survival of new seeds into the next season; and (viii) the survival of old (non-germinated) seeds into the next season. The ability of a given seed to reach each successive stage is governed by transition probabilities, the value of which are dependent on the adoption of Striga control practices. The most general form of the model is represented by Equation (1).

\[ X_{t+1} = (X_t - G_t)*(1 - MR_{OLD}) + NEW_t*(1 - MR_{NEW}) \]

Where:  
- \( X_t \) = number of viable seeds in the soil at the beginning of season t  
- \( G_t \) = number of seeds that germinate at the beginning of season t  
- \( NEW_t \) = number of new seeds introduced into the field at the end of season t  
- \( MR_{OLD} \) = probability a seed that did not germinate during season t dies before the beginning of season t+1 (i.e., mortality rate of old seeds)  
- \( MR_{NEW} \) = probability a seed introduced to the field at the end of season t dies before the beginning of season t+1 (i.e., mortality rate of new seeds)

The number of seeds that germinate is dependent on the number of seeds in the soil (\( X_t \)), the probability that those seeds are stimulated by root exudate (\( P_S \)), and the probability that the stimulated seeds germinate (\( P_G \)). The probability of stimulation is modeled as a function of host plant density (\( W \)) and the application of urea fertilizer (Urea). \( P_G \) enters the model as a fixed value. Equation (2) represents the number of germinated seeds per m². Table 1 presents the parameter values used in the biological model as well as the sources from which those values were derived.

\[ G_t = X_t * P_S(W, Urea) * P_G \]

Where  
- \( W \) = number of host plants per m²  
- Urea = kg of Urea applied per hectare

To account for the seed externality, the number of new seeds introduced into the field at the end of season t is comprised of three elements: (1) the number of seeds produced in one’s own fields in season t; (2) the proportion of new seeds produced in one’s own fields that migrate out of those fields; and (3) the number of new seeds produced in the fields of one’s neighbors that migrate into one’s own fields. The first
element is endogenous. The other two are initially taken to be exogenous and then subjected to sensitivity analysis to examine the impact of the seed externality on the solution to the model.

\[
(3) \quad \text{NEW}_t = \text{X}_t \times P_S(W, \text{Urea}) \times P_G \times P_A(N) \times P_E(W, \text{Urea}, N) \times P_R(\text{Weed}) \times \text{Seeds}_t \times (1 - \text{OUT}) + \text{IN}
\]

Where
- \( P_A \) = probability a germinated seed attaches to a host root
- \( P_E \) = probability an attached parasite emerges above the soil
- \( P_R \) = probability an emerged parasite matures to reproductive capacity
- \( \text{Seeds} \) = number of seeds produced per mature parasite
- \( \text{OUT} \) = proportion of seeds produced in one’s own fields that migrate out of those fields
- \( \text{IN} \) = number of new seeds that migrate into one’s own fields from neighboring fields
- \( N \) = kg of nitrogen applied per hectare
- \( \text{Weed} \) = number of person days spent weeding

The model assumes that, within a given field, seeds are evenly distributed in the soil. Therefore, each seed has an equal probability of being stimulated by host root exudate.

**Section 3 Economic Component**

Agricultural production in Mourdia is undertaken by extended families known as production units (UPs). Land is allocated to each UP through a council of elders. Within the UP, the household head partitions some of the land among the nuclear families, reserving the bulk of the acreage for communal fields – fields tended by and whose harvest benefits the entire UP. The communal fields are dedicated to the production of staple cereals, and are thus most susceptible to *Striga* infestation. With this in mind, the economic component is specified to maximize returns to cereal production on the communal fields subject to the resource constraints faced by a representative UP.

The general form of the economic component is represented by Equation (4). The discount rate, initial *Striga* infestation level, and all prices are exogenously determined.

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1 Herbicides are not incorporated into the model as they are not available in the study area.
2 Synthetic stimulants are not available for use in the study area.
\[(4) \quad \max \sum_{\text{control, } t} \sum_{i} B^{t-1} \{P_{i,t} \cdot Y_{i,t}(X_{i}, \text{Control}_{i, j, t}) \cdot HA_{i, t} - \text{Cost}_{i,t}(\text{Control}_{i, j, t})\} \]

Subject to:

\[X_{t+1} = f(X_{t}, \text{Control}_{i, j, t}, \text{New}_{IN, t}, \text{MR}_{OLD}, \text{MR}_{NEW})\]

\[\sum HA_{i, t} \leq \text{Total UP acreage for communal fields}\]

\[\sum Control_{i, j, t} \leq \text{maximum available Control}_{j, t} \forall j\]

\[\text{Cost}_{i, t} \leq \text{Budget Constraint}\]

\[X_{1} = X_{1}^*, \text{ given}\]

Where:

\[B = \text{the discount rate}\]

\[P_{i, t} = \text{unit price of commodity } i \text{ at time } t\]

\[Y_{i, t} = \text{per hectare harvested yield of commodity } i \text{ at time } t, \text{ a function of Striga control and the number of parasites.}\]

\[\text{Cost}_{i, t} = \text{cost of producing commodity } i \text{ at time } t\]

\[\text{Control}_{i, j, t} = \text{level of Striga control measure } j \text{ employed in the production of commodity } i \text{ at time } t\]

\[n = \text{number of years in the farmer’s planning horizon}\]

All other variables are as described in the preceding section.

Three crop associations are considered in the model: millet in pure stands, millet inter-cropped with Striga resistant cowpea variety “IT 89KD 245,” and millet inter-cropped with groundnut. Per hectare cowpea and groundnut yields enter the model as fixed values based on secondary data. Millet production is a function of crop density, the number of Striga attached to the host, and the amount of nitrogen applied per hectare. The production functions of each crop and the parameter values of the economic component, along with their sources, are presented in Table 2.

To determine the length of time for which the model should be run, a questionnaire was designed and administered by the IPM-CRSP/Mali project. Optimally, the number of years the model is run should correspond to the length of the UPs’ planning horizon in Mourdiah. However, the notion of an economic planning horizon was considered too abstract for the farmers, so the survey employed a proxy. Planned crop rotations were considered a reasonable proxy for the lower bound of a farmer’s planning horizon – a

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3 While a whole farm model would have been preferable, data were not available for a more extensive analysis.
farmer may be planning beyond the length of a rotation, but if a rotation is used it is evidence of planned
economic activity for at least as long as the duration of the rotation.

In the 1980’s, Caldwell et al. tried to elicit rotational information from farmers in Mali and found
that the farmers did not employ fixed crop rotations. Rather, rotational decisions were made on a yearly
basis. With that in mind, planned periods of fallow were used as the proxy for the lower bound of the
planning horizon.\(^4\)

The average number of years a field is planned to be fallowed is 2.6. T-tests of the survey results
reveal the average is statistically different than one at \(p=0.05\), but not different than three. The model is,
therefore, run for three years.

Section 4 Results

Millet in Mourdiah is grown predominantly in pure stands at a density of 1 millet hill per \(m^2\)
(IPM-CRSP/Mali, 1995). Furthermore, farmers generally do not weed *Striga* because they have not seen a
correlation between current yields and weeding, nor is urea purchased for application to millet fields (IPM-
CRSP/Mali, 1995). The implications of this cropping strategy on the growth of the *Striga* seedbank and,
ultimately, on the ability of the UP to meet its nutritional needs are reflected in Figures 1 and 2.

Table 3 presents the solution to the model for a representative household in Mourdiah, with an
initial seedbank of 10,000 seeds/m\(^2\), under four scenarios: (1) farmers follow the traditional cropping
pattern of pure millet stands at a density of 1 plant/m\(^2\); (2) farmers choose from the three model crop
associations over a 1-year horizon, without the seed externality; (3) the same opportunity set as in (2), but
with a 3-year horizon; and (4) the same opportunity set and planning horizon as (3), but with the seed
externality. When the model is permitted to choose between crop associations, the millet-cowpea
association is chosen each year irrespective of the length of the planning horizon and presence of the seed
externality. When the planning horizon is extended from one to three years, weeding in the first two years
becomes profitable. In fact, it pays to remove all *Striga* capable of setting new seed.

\(^4\) The notion of a “planning horizon” is used loosely in this context. We do not contend that farmers are
planning all of their economic activity over the duration of the fallow period. The farmers’ lack of planned
rotations is evidence that they are not doing so. However, the planned fallow period reveals that farmers
are making some economic decisions (i.e., which fields to take out of production) over that period. This
project is interested in delivering *Striga* control packages that inherently require more than one season for
returns to be garnered. We feel that if farmers make, in advance, some economic decisions over the length
Table 4 presents the net present value of production and the amount of the UP’s nutrient requirement that is met under each scenario. The millet-cowpea association generates financial higher returns in Year 1 than the traditional pure millet production scheme regardless of the length of the planning horizon. More importantly, however, the millet-cowpea association also increases the ability of the UP to meet its nutrient needs in the first year. In other words, adoption of the millet-cowpea association generates both nutritional and financial returns to the millet-cowpea association the first season it is employed.

After the first year, however, the length of the planning horizon has a significant impact on the UP’s nutrient production. Nutrient production under both single season strategies falls in each successive year, whereas it increases each year in both 3-year strategies. That is, significant nutritional returns to weeding may be realized after a lag of just one season.

So, which of the barriers to adoption have prevented farmers from adopting the millet-cowpea association? Information. Prior to the on-farm IPM-CRSP/Mali trials conducted in Mourdiah, farmers were unaware of the expected returns to inter-cropping millet with cowpea variety “IT 89KD 245” (IPM-CRSP/Mali, 1995). In fact, the farmers were not aware of the availability of “IT 89KD 245” (IPM-CRSP/Mali, 1995).

While “IT 89KD 245” is an exotic Striga control, weeding has always been available to farmers in Mourdiah. Why, then, do farmers fail to weed their fields? Of the potential barriers to adoption, again it is information that appears to be the problem. Sensitivity analysis reveals that weeding does not leave the basis of the solution until the discount rate is approximately 0.3, which is extremely low. The presence of the externality also does not appear to be relevant, as weeding is employed regardless of whether or not there is an externality; and the land, cash and weeding labor constraints are not binding.

To overcome the information gap regarding the nutritional and financial returns to weeding, the IPM-CRSP/Mali is currently designing a new set of field trials to test/demonstrate the effect of weeding on the millet-cowpea association. The trials are to be conducted in Mourdiah with local farmers participating in both the implementation and monitoring of the trials. It is anticipated that this “participatory” approach will overcome the information gap and lead to a high rate of adoption.

of the fallow period, they are likely to consider making other advance decisions (i.e., allocation of Striga control measures) over that period as well.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_S$</td>
<td>$(1-\exp(-0.1<em>W)) \cdot 0.878 \cdot \exp(-0.003</em>\text{Urea})$</td>
<td>Kunisch et al. Estimated&lt;sup&gt;5,6&lt;/sup&gt;</td>
</tr>
<tr>
<td>$P_G$</td>
<td>0.5</td>
<td>Kunisch et al., SH&amp;W, S&amp;W</td>
</tr>
<tr>
<td>$P_A$</td>
<td>$0.012 \cdot \exp(0.071<em>N - 0.0007</em>N^2)$</td>
<td>SH&amp;W Estimated&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>$P_E$</td>
<td>$50<em>W/(50</em>W + X_A)$</td>
<td>Kunisch et al., SH&amp;W, S&amp;W&lt;sup&gt;8&lt;/sup&gt;</td>
</tr>
<tr>
<td>$P_R$</td>
<td>$0.34 \cdot (1 - 0.25*\text{Weed} / X_E)$</td>
<td>W&amp;S Estimated&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td>Seeds</td>
<td>11,000</td>
<td>S&amp;W</td>
</tr>
<tr>
<td>OUT</td>
<td>0.01</td>
<td>Initial Starting Value</td>
</tr>
<tr>
<td>IN</td>
<td>440</td>
<td>Estimated&lt;sup&gt;10&lt;/sup&gt;</td>
</tr>
<tr>
<td>$MR_{\text{NEW}}$</td>
<td>0.1</td>
<td>Kunisch et al.</td>
</tr>
<tr>
<td>$MR_{\text{OLD}}$</td>
<td>0.45</td>
<td>Kunisch et al.</td>
</tr>
</tbody>
</table>

<sup>5</sup> The baseline, $(1-\exp(-0.1*W))$ is from Kunisch et al. The effect of Urea is estimated by non-linear least squares using data from Bebawi et al. (1991). All coefficients are significantly different than zero at p=0.0001 (adjusted $R^2 = 0.9128$).

<sup>6</sup> The probability of stimulation is also discounted depending on the crop association planted. Millet in pure stands is not discounted. $P_S$ for a millet-cowpea association is reduced 66% based on Dembele et al. (1997). $P_S$ for a millet-groundnut association is reduced 43% based on Salle et al. (1987) and Konate (1987).

<sup>7</sup> The baseline, 0.012, is taken from SH&W. The effect of nitrogen was estimated by non-linear least squares with data from Ogborn (1987), Hess and Ejeta (1987), Boukar, Hess and Payne (1996), and Gworgwor and Weber (1991). All coefficient estimates are significantly different than zero at p=0.0001 (adjusted $R^2 = 0.5784$).

<sup>8</sup> The number of parasites per m<sup>2</sup>, $X_A = X_t \cdot P_S \cdot P_G \cdot P_A$.

<sup>9</sup> Baseline of 0.34 is from Webb and Smith (1996). The effect of weeding is from Setty et al. (1987). A logical constraint is included in the GAMS program to ensure $P_R \geq 0$, that is, one cannot weed more than the number of weeds.

<sup>10</sup> Based on a seedbank of 10,000 seeds/m<sup>2</sup>, host plant density of 1/m<sup>2</sup>, no urea, nitrogen, or weeding applied to the field, and a migration rate of 0.01.
<table>
<thead>
<tr>
<th>Parameter/Production Function</th>
<th>Value/Functional Form</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Rate ($B$)</td>
<td>0.8</td>
<td>Estimated&lt;sup&gt;11&lt;/sup&gt;</td>
</tr>
<tr>
<td>Millet Production (kg/ha)&lt;sup&gt;12,13&lt;/sup&gt;</td>
<td>$30.86<em>W + \frac{(348.7 + 10.5</em>N)}{(1 + 0.1*Parasite)}$</td>
<td>Christianson and Vlek (1991), Webb and Smith (1996)</td>
</tr>
<tr>
<td>Groundnut Production (kg/ha)</td>
<td>250</td>
<td>Salle et al. (1987)</td>
</tr>
<tr>
<td>Cowpea Production (kg/ha)</td>
<td>30</td>
<td>Yeboah and Guthrie (1995)</td>
</tr>
<tr>
<td>Model Planning Horizon (years)</td>
<td>3</td>
<td>Estimated</td>
</tr>
<tr>
<td>Price of Urea (CFA/kg)&lt;sup&gt;14&lt;/sup&gt;</td>
<td>178.5</td>
<td>I. E. R. (1997)</td>
</tr>
<tr>
<td>Price of Weeding Labor (CFA/day)</td>
<td>200</td>
<td>IPM-CRSP/Mali (1995)</td>
</tr>
<tr>
<td>Land Available (ha)&lt;sup&gt;15&lt;/sup&gt;</td>
<td>21.25</td>
<td>IPM-CRSP/Mali (1995)</td>
</tr>
<tr>
<td>Cash Available (CFA)</td>
<td>30,000</td>
<td>IPM-CRSP/Mali (1995)</td>
</tr>
<tr>
<td>Labor Available for Harvest</td>
<td>169.75</td>
<td>IPM-CRSP/Mali (1995)</td>
</tr>
</tbody>
</table>

<sup>11</sup> Based on interest paid on loans for agricultural inputs (L’Institute D’Economie Rurale, 1997).
<sup>12</sup> When inter-cropped with groundnut, millet density is fixed at 2.5 millet plants/m², and millet yield is reduced 50%, both based on Salle et al. (1987), latter based also on Konate (1985?).
<sup>13</sup> When inter-cropped with cowpea, millet yield is not reduced based on Dembele et al. (1997).
<sup>14</sup> Urea has the highest nitrogen content and is also the cheapest of all nitrogen fertilizers. For this reason other fertilizers, e.g. ammonium phosphate, are not incorporated into the model.
<sup>15</sup> Land, cash, and labor availability based on representative household in Mourdiah.
Figure 1: Growth of *Striga* Seedbank over Time
(Millet Density = 1/m², Nitrogen = 0, No Weeding)

Figure 2: UP Nutrition Requirement Met (%) Versus Seedbank Density
Table 3: Model Solution With and Without the Externality, Initial Seedbank=10,000/m²

<table>
<thead>
<tr>
<th>Year</th>
<th>Externality</th>
<th>Planning Horizon</th>
<th>Seedbank</th>
<th>Crops Grown</th>
<th>Millet Density</th>
<th>Urea (kg/ha)</th>
<th>Pre-Harvest Weeding</th>
<th>Post-Harvest Weeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>1</td>
<td>10,000</td>
<td>Millet</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1</td>
<td>10,000</td>
<td>Millet-Cowpea</td>
<td>2.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3</td>
<td>10,000</td>
<td>Millet-Cowpea</td>
<td>2.6</td>
<td>0</td>
<td>0</td>
<td>7.75</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>3</td>
<td>10,000</td>
<td>Millet-Cowpea</td>
<td>2.6</td>
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<td>0</td>
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<td></td>
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<td>11,788</td>
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<td></td>
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<td></td>
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<td>5,871</td>
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<td>0</td>
<td>4.6</td>
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<td>3</td>
<td>No</td>
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<td>16,269</td>
<td>Millet</td>
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<td>0</td>
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<td></td>
<td>No</td>
<td>1</td>
<td>13,855</td>
<td>Millet-Cowpea</td>
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<tr>
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<td>No</td>
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<td>2,905</td>
<td>Millet-Cowpea</td>
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<td>0</td>
<td>0</td>
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<tr>
<td></td>
<td>Yes</td>
<td>3</td>
<td>3,849</td>
<td>Millet-Cowpea</td>
<td>2.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</table>
Table 4: Present Value of Net Returns and Percent UP Nutrient Requirement Met
Under each Cropping Scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Planning Horizon</th>
<th>Externality</th>
<th>Crop</th>
<th>Present Value of Net Returns</th>
<th>% UP Nutrient Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>No</td>
<td>Millet</td>
<td>96,270</td>
<td>15.2%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>Milt-Cowpea</td>
<td>127,500</td>
<td>20.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>Milt-Cowpea</td>
<td>116,500</td>
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References


