Geospatial Analysis of Cotton Production Potential in Sub-Saharan Africa

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Abstract. This study applies a geospatial analytic approach to assess human, economic and physical constraints to cotton production potential in Mali, Burkina Faso and Benin. A Geographic Information System (GIS) is used to create a cost grid reflecting an integrated, geographic model of cotton production potential including a theoretically diverse set of parameters. Parameters include infrastructure, socio-political, demographic, agronomic, and novel geographic parameters among others. The GIS model uses geostatistics and cost grid functions to explore and expand upon existing datasets. The study results in a visual representation of cotton production potential.

Keywords. Sub-Saharan Africa; geospatial analysis; GIS; cotton; agriculture; production potential

1 Introduction and Problem Statement*

This study applies a geospatial analytic approach to assess human, economic and physical constraints to cotton production potential in Mali, Burkina Faso and Benin. A Geographic Information System (GIS) is used to create a cost grid reflecting a theoretically diverse set of parameters including infrastructure, socio-political, demographic, agronomic, and geographic parameters among others. Although still in early stages, the goal of this model is to allow policy makers, investors, or academic researchers to evaluate hypothesized scenarios for the cotton sub-sector.

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* All figures and tables are available at: <www.geog.mcgill.ca/grad/green/CPP>.

Cotton plays an important role in the economies and societies of Sub-Saharan Africa (SSA). It is estimated that up to 16 million people directly or indirectly benefit from the cotton production economy generated by between two and three million of the region's small farmers [13]. In fact, the combined region of West and Central Africa is set to become the world's second largest exporting region of cotton after the United States. Cotton production in West Africa has rapidly increased over recent decades, rising from some 150,000 tons of cotton lint in the 1970s to over one million tons in 2003-2004 [13]. Despite this increase, variability in parameters influencing cotton production creates a spatially heterogeneous landscape for cotton production in SSA [8, 10]. The purpose of this paper is to apply a transparent, integrative, and parsimonious model to geographically understand what factors limit cotton production potential in the region. The three countries targeted in this study - *Mali, Burkina Faso,* and *Benin* -were chosen because of their economies' high dependency on cotton and because they are among the largest cotton producers in SSA [4]. Moreover, given the significance of cotton for the livelihood of millions people in the region, the potential benefits of a successful cotton industry could have a wide-spread impact on society as a whole.

Cotton production potential (CPP) in West and Central African countries is a dynamic system conditional, like many human-environment systems, on complex trends (ecologic, demographic, political, economic, etc.) that interact on multiple scales (global, regional, national, provincial, household, and individual) [2]. There are many approaches to measuring commodity production potential that use political, agronomic, or other limited sets of variables [5, 13, 21]. However, these approaches are often not integrated or comprehensive in scope, focusing only on one theoretically isolated set of variables as opposed to examining how parameters interact in combination with each other. Moreover, these approaches do not usually provide models with explicit manipulable parameters allowing comparative regional studies.

One possible way of combining, visualizing, and evaluating these parameters is by operationalization in a GIS. The advantage of using GIS stems from the fact that they require specific parameters, provide manipulable conditions, and are geographically referenced. By requiring that information be spatially explicit, a GIS can identify areas of potential growth or pattern anomaly which can then be investigated to understand how policy may play a role in promoting development.

With cotton being an input-intensive crop, its production inevitably raises questions as to its environmental impact and long-term sustainability. The central elements in expanding cotton yields over the last decades have generally been input-related, focusing on enhancing irrigation as well as fertilizer and pesticide use. However, it is precisely this strategy that is also a source of environmental degradation [1], often leading to soil degradation and decline in soil fertility [3]. The following sustainability problems have been reported in relation to cotton cultivation [14]: degraded land as a result of salinization and erosion; water depletion by excessive use of soil and surface water; natural habitat conversion due to cutting of forests and dam constructions; eutrophication of surface water; wildlife contamination by pesticides (insects, fish, mammals, birds); human health due to direct pesticide intake primarily by farm workers but also by regional inhabitants through contamination of drinking water and food contamination. Furthermore, the monoculture characteristic of cotton often adds to the destructive effect on natural habitats as farmers expand their production areas to increase yields. Cotton fields often lack vegetative cover and organic matter to limit the impact of soil erosion [3, 26]. All these factors have very serious implications for intensive and wide-spread cotton production for long-term sustainability.

This model provides a tool to identify areas for future production and the constraints that limit those areas. The ongoing development of the CPP model recognizes that cotton growth areas in Africa are ever changing [13], but sees benefit in attempting to understand the complex systems of agency and structural constraints to sustainable production.

2 Methods

This section describes procedural steps in data selection, parameter scaling and weighing, and construction of a GIS reflecting geographic patterns of cotton production potential. The ultimate goal of these processes is to construct a cost grid [29] that reflects the most likely areas for cotton expansion in Mali, Burkina Faso, and Benin. In the CPP MODEL cost grid, low value cells are considered to be more likely to be available for cotton expansion and higher value cells are less likely to have cotton. The possible min-max range for pixel values in the cost grid is 0-485, though the true range of values (185.24-325.07) is much smaller.

2.1 Parameter Selection

Preliminary parameter selection was modified by data availability and reliability, which are problems for human-environment models in general [22] and for the cotton sub-sector of SSA in particular. The 33 parameters selected for this model are presented in *Table 1*. Reducing the parameters, specifically those based on coarse or unreliable data is seen as a next step for this model. The current parameters were divided into three heuristic categories: economic, human, and physical assets or capitals. The division of the parameters into these three groups is a heuristic device that does not necessarily reflect any version of capital theories [23-25]. The divisions are manipulable and do not ultimately change the model outcome because every parameter is independently scaled and weighed.

2.2 Parameter Processing: Scaling and Weighing

Parameter data must be scaled and given a specific weight relative to all other parameters. Scaling of the data reflects levels of heterogeneity, statistical patterns, and social categories in data. Weighing the data gives each scale a relative value which defines relationships between parameters. The scaling and weighing of parameters were undertaken in static equilibrium. Complex system interactions [12] and emergent properties were not given dynamic, longitudinal equations. Although, modeling of the complex, dynamic relationships that exist between parameters is ultimately necessary for scenario development. Modeling these relationships is also viewed as a next step for the CPP model.

National Scale

Data came in scales at and below the national scale. Different methods were applied to datasets due to the way that GIS recognize raster and vector data at different scales and due to data quality (preclassified or raw). Most of the parameters (23/33) lacked disaggregated data below the national scale. These parameters are presented in *Table 2*. Since these were all processed in a similar fashion, the scaling and weighing of one of these parameters (*Arable Land*) is presented here in detail as an example of the basic procedures.

Arable Land

This parameter is judged to be an indicator of land that is most likely for the extension of commercial crops and by inference cotton expansion in SSA where the large majority of cotton is grown on 1-2 ha. plots by small farmers. Reliability of the data suffers in the data acquisition stage. Data was reported individually by different countries that may have different data standards or definitions. The average hectares for the years 1997-2002 was classified against all SSA countries on a relative scale of 0-4 using Jenks' Natural Breaks formula [17-18]. A weight of "*2" was applied to the scale making a maximum score of eight for the parameter. The lower the value, the better performing a parameter. The final scores (*Table 3*) were converted into raster grids representing the three countries.

Subnational Scale

Ten of CPP model's 33 variables represented phenomena at the subnational scale. Various methods were needed to operationalize, scale, and weigh this data. Two of the parameters (*Distance to Ginneries* and *Distance to Cities*) were originally vector files that were converted to raster and then processed using the Straight-line Distance function in Spatial Analyst (ArcGIS). The results of this process were raster grids that expressed distance to center points (cities and ginneries) in kilometers. Classification of these grids supposed that distances of 70 km intervals served as effective class levels for farmers trying to reach markets and transport to ginneries.

The reclassification of the grids for many parameters took place on data that had already been classified. For example, *Problem Soils, Terrestrial Ecoregions, Historic Cotton Areas,* and *Road Conditions* parameters came as preclassified datasets that had to be reclassified in relation to the growth and transport of cotton. These processes are detailed in *Table 4*. Unfortunately, estimates of Producer and User Accuracy were not available for all the preclassified data received. Technical sheets from the FAO Land and Water Development division[1] determined parameters of cotton growth and scales. Some of the subnational parameters (*Precipitation* and *Population Density*) were subjected to Jenks or manual data reclassifications, but unlike the national level data, this was done in relation to the data values in the grid itself and not to other SSA countries or administrative districts. All grids were clipped to represent Mali, Burkina Faso, and Benin.

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[1] <http://www.fao.org/ag/agl/default.stm>

2.3 Stepwise Procedures: Cost Grid and Statistical Validation

Once all data was in raster format it was subjected to the basic, cell-based analysis and geoprocessing procedures following [28] to form a cost grid.[2] The resulting datasets express the value of all land in the region for cotton production potential at a 1 km resolution (pixel).

As mentioned above, validation of the model is limited by data constraints. Ground truth data acquisition will take place in the next stage of the model. Despite this, there is a need to compare our data results against some common standards. We cross-validate the model against datasets representing historic provincial cotton production data for 2002 from the Sahel West African Club (SWAC) [13] and an agroecological model developed by the FAO and IIASA [5].[3] We compare these datasets at the lowest administrative level, though in full realization that the scale of SWAC data biases results and limits inferences below the provincial level.

In order to compare the models some data standardization was necessary. Data values for all three models were summarized at the lowest administrative level in Mali, Benin, and Burkina Faso. Data thus summarized was then reclassified according to a ranking system of eight hierarchical steps based on IIASA data. *Table 5* shows that SWAC and CPP administrative units are classified by range (for SWAC production in metric tons and for CPP mean values) whereas the IIASA values were reclassified based on median values due to the more conservative estimate of *Very High* values that median provided over mean for IIASA.

The IIASA pixel resolution of 9 km was based on a multitude of ecological parameters that they detail in their methodology.[4] We collapsed the original 0-*NoData* and 9-*Water* values with *Not Suitable* to form the category *Very Marginal*. The SWAC data was problematic in that we were not able to get data at the lowest administrative levels by the time this paper was being written, therefore provincial level production data was disaggregated to lower administrative levels. The raw SWAC provincial scale production numbers were grouped into an eight step hierarchy similar to the IIASA model. After rank ordering the historic production capability per province, we assumed that all lower administrative levels would maintain an equal ranking relative to each other. Finally, since it was difficult to assign a contextualized understanding of the data produced in our model, we used Jenks to classify our model into eight divisions like SWAC and IIASA schemes. *Figure 1* shows the general distribution of the administrative units by rank for each model. The reclassification results (*Table 6)* indicate that the classification structure was sufficient in producing similar kurtosis and standard errors in the model datasets.

Exploratory statistical analyses were performed on the data sets at regional and national scales to observe how the models correlated regionally and when national units were considered. Administrative units were subjected to ANOVA tests at both the regional and national scales. Correlation matrices allowed observation of directionality between the models. Overall accuracy was calculated by smallest administrative unit for the entire region. Kappa Index of Agreement (KIA) was

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[2] Specific procedural steps are available at: <www.geog.mcgill.ca/grad/green/CPP>.

[3] We refer to the FAO/IIASA model as just *IIASA* for the remainder of the article

[4] <http://www.fao.org/AG/agl/agll/gaez/index.htm>

performed on raster versions of the smallest administration units. All subsequent maps were produced in ESRI ArcGIS 9.1. Results are presented as both statistics and maps to help visualize data relationships.

3 Results

Parameter values at the national scale are reported in *Table 7*. Visual comparison of the economic, human, and physical maps (*Figures 2-4*) reveals spatial heterogeneity at the pixel level and how coarse national scale parameters can heavily influence cost grid scores. The outlines of the Economic Assets map (*Figure 2*) reflect parameters at the national scale; whereas the Physical and Human Assets maps (*Figures 3 & 4*) better represent the results of incorporating localized data. Differences in the capital assets maps scores reflect how much weight was given to parameters for the cost grid calculation. The physical infrastructure dimension was nearly equivalent to the combined values of economic and human dimensions. *Table 8* summarizes the physical, economic, and human descriptive statistics over the entire region. These three grids combine to form the overall cost grid in *Figure 5*. The final cost grid shows cotton production potential to be highest in sections of western Mali, near Mopti in Mali, close to bodies of water, in a belt through the mid and southern reaches of Burkina Faso, and in the northern areas of Benin.

The SWAC and IIASA models were introduced in order to compare and validate the results of the CPP model. Neither SWAC nor IIASA represent true cotton production potential; they are useful comparative models for drawing inferences about the accuracy and relevancy of the CPP map. Maps of the administrative level groupings are shown in *Figures 6-8*. Descriptive statistics for the administrative divisions of model data at the regional level are presented in *Table 9*.

Pixels classified according to the eight step hierarchy were examined through the use of a Kappa Index of Agreement test (KIA) (*see Table 10*) [19]. The results indicate poor agreement of the CPP model with the IIASA and SWAC models at the pixel level. IIASA and CPP show better agreement than the SWAC and CPP. Overall accuracy assessments of the models' pixels were high (49%) between CPP and the SWAC and IIASA models. However, due to the numerical bias of using pixels from the agreeably unsuitable land in northern Mali, we prefer to use the administrative levels as a better measure for overall accuracy. Aggregating pixel values to local administrative levels, the models were statistically compared. Out of the 650 administrative units, 106 were similarly classified by CPP and IIASA, 41 were similarly classified by CPP and SWAC, and 34 were classified as the same value by all three models (see *Table 11*). It must be recalled that we are evaluating CPP against non-ground truth models. Given that the models do not represent reality, we chose to represent the data from CPP and focus on *Producer's Accuracy* here. *Figure 9* shows the agreement between administrative units at each rank of the classification hierarchy. The figure closely resembles *Producer's Accuracy*. The highest amount of agreement occurs in *Unsuitable* land.

ANOVA *F-value* (83.52) on the models (*Table 12*) shows that there is a significant difference between the model means. The correlation matrix (*Table 13*) illustrates that CPP model mildly agrees with the IIASA model ($r= 0.52$, $r^2= 0.27$).

Whereas there is no explanatory value between SWAC and CPP (r= -0.10, r^2= 0.01). The SWAC and IIASA model also had a low correlation (r= 0.27, r^2= 0.07). None of the models showed a high level of agreement in either their raw data (Kappa) or at the lowest administrative levels (ANOVA and Correlation Matrix), SWAC diverging more than the other two models.

Statistics comparing model performance at the national levels were undertaken to inspect how models differed in the relative understanding of national capacities. Descriptive statistics for models in each country are presented in *Table 14*. ANOVA tests performed on models for every country (see *Table 15*) found that there was no significant difference in the way that models judged Benin, though Mali and particularly Burkina Faso showed high levels of disagreement of cotton production potential. Correlation matrices inspect the correlation of trends in administrative values between each model. CPP found that the best country was Burkina Faso while Mali and Benin ranked equally. IIASA also found that Burkina Faso outranked Benin and Mali (see *Table 14*). In contrast, SWAC found that Mali's potential for cotton growth was much higher than Benin and that Burkina Faso was a marginal area. While a relative ranking of the countries is interesting, more detailed analysis of model performance in each country will allow us to see how the models performed differently.

Mali

There was significant performance difference between models in Mali (ANOVA: $p < 0.001$) (*Table 15*). There is much disagreement in western Mali where IIASA rates the region poorly, CPP rates it as marginal, and SWAC shows significant levels of production. SWAC with a mean score of 2.7 rates Mali generally higher than IIASA (4.5) and CPP (4.5) mean scores. Correlations were all strong and significant. Model correlations were strongest for CPP and IIASA (r=0.66, r^2=0.44) (*Table 16*). When inspecting spatial heterogeneity by administrative level, one can see that the large amount of unusable land in the north, the usable land near Mopti and near water bodies, and the usable land in the southern parts of Mali correlate well in all models.

Benin

ANOVA tests found no significant difference between the models in Benin. Thus the models judged the country at about the same value. However, visual inspection of the models shows that there is much disagreement in the southern provinces and in the relative scaling of the districts. In fact, the correlation matrices indicate that there was a weak, non-significant correlation between SWAC and CPP. IIASA and CPP show a medium correlation based on their relative ranking of administrative levels and the higher spatial diversity they show than the SWAC model.

Burkina Faso

Burkina Faso revealed the highest significant differences in the model (ANOVA: $p<0.001$) due to the divergent predictions made by SWAC. CPP and IIASA generally agreed on Burkina Faso as the best country (mean values: CPP 1.72, IIASA 2.78) at the national level while SWAC found it to be the worst producing country (mean value: SWAC 6.06). Administrative levels showed interesting correlation patterns: CPP and SWAC showing a medium negative correlation, SWAC and IIASA showing a medium positive correlation, and CPP and IIASA showing only a weak positive correlation. CPP generally agrees with IIASA in the western and eastern areas of the country. SWAC and CPP predict opposing trends through the middle, north, and eastern regions of the country.

4 Discussion

Constraints to data and to how parameters are constructed limit inferences. Selection of model parameters is constrained by availability and reliability of data [17, 22]. Human factors and physical factors limit acquisition and operationalization of reliable data for models of human-environment interfaces [22]. A discussion of general limitations to data acquisition for human-environment interface models can be found in Rindfuss *et al* (2003), Lambin *et al* (2003), and Meyer & Turner (1994) [17-18, 22]. There is a paucity of data in SSA due to human and physical constraints to data acquisition. Particular constraints to data reliability and acquisition for the cotton sub-sector in SSA are numerous. The main practical hurdle we faced was that data on local and provincial institutions or the localized actions of national institutions involved in the cotton sub-sector were not available. Problems of data reliability and operationalization related to each selected parameter of this model are summarized in the tables presenting national and subnational scale parameters in *Tables 2 & 4*. There is much room for improvement in the CPP model. Lack of rigorous data ultimately led us to generate new datasets, attempt to rescale data, or to omit and modify the selection of parameters used in the model.

Some problems with data reliability can be overcome by ground-truthing a model or comparing a model to other datasets. However, reliable and appropriate data must be available or acquired for validation [16, 22]. Similar constraints to raw data acquisition in SSA limit validation methods and possibilities to draw conclusions from comparison with other datasets [17, 22]. Other problems that were common to both human and ecological parameters included data anachronism. In dynamic systems, remote sensing and other methods may reflect onetime events rather than trends. Also, while certain practices of land management or institutional settings may be in place, there is often a time lag before clear causal results of these practices or relations can be empirically measured. Even when results are measured and accrued to specific management practices or institutional settings there are problems of equifinality and multifinality [7]. When possible, efforts were made to incorporate the amplitude of change, slope of change, consideration of possible time lag, consideration of equifinality and multifinality, and other longitudinal data characteristics into the model. The limits of reliable data pose a great hurdle to our understanding of aspects of human-environment interface and to our ability to create appropriate policy to adapt to these conditions.

CPP Model and Comparisons

The CPP model tells us that large swaths of northern Mali are unsuitable for cotton production. Other models agree on this point. However, there are many areas of disagreement. The CPP model projects large areas in Burkina Faso and the country itself as the best places for cotton production.

The most significant difference between the models was in the case of Burkina Faso, which scored particularly well in terms of its economic and physical parameters. Producer price related variables, indicating a stable institutional setting, were better for Burkina Faso than for either Mali or Benin (see *Table 7*). Burkina Faso's Textile Fibres Company (SOFITEX) is the largest operator in the country's cotton sector and although it holds a monopolistic position for the sale of production inputs, producers are very much involved in the management of the company [10, 27]. The strong involvement of producers in the management of the sector may explain Burkina Faso's economic parameter performance. High producer participation would in this case translate into the ability of institutions to lower costs and maintain consistent producer costs and would also indicate the efficiency and adaptability (reforms) of the institutional setting.

While the CPP and IIASA models generally agreed Burkina Faso had the best cotton production potential at national level, SWAC found it to be the worst. This discrepancy could have several explanations. First, the models themselves have fundamental differences in measurements. SWAC is based on historic production data while the CPP and IIASA models measure multiple parameters affecting production. Models that focus on the interplay of a variety of factors may be better for measuring potential. Second, cotton plantation areas shift regularly in West Africa in response to climatic factors (availability of water and fertility of soils) [13]. The SWAC model at a given point in time and does not take into account longitudinal trends. While all three countries' overall production dipped in 2002, production levels increased again in the period between 2003 and 2005 (see *Figure 10*). The IIASA and CPP models paint a less stark picture than SWAC because they look at multiple, long term parameters. Moreover, there are other than agroecological factors at play that explain increased production in 2003 and 2005. This is where the more multifaceted CPP model provides a more nuanced insight than IIASA, accounting for economic and human factors in addition to agroecological trends. Third, CPP's physical parameters play a large role in why Burkina Faso did so well compared to other regions. Perhaps most influential of all the physical parameters are cattle distribution and the lack of an independent parameter reflecting landscape slope. The CPP model includes a variable accounting for problem soils (which indicates sloped lands as a problem), but the CPP model maps do not account for the poor growing regions around the Mossi Plateau in central Burkina Faso. These regions are included in the IIASA maps, and significantly downgrade the areas for cotton production. Lastly, the way in which the models' raw data is classified (in the eight step hierarchy) may be the ultimate source of disagreement. Without a way to calibrate the CPP pixel values to actual points on the land, the classification hierarchy is ultimately flawed.

In the CPP model, Burkina Faso did well due to the density of quality roads, better cattle distribution, and high amount of potential irrigation land. These factors raised the quality of Burkina Faso while at the same time downgrading places like western Mali where SWAC showed higher production levels than either of the other models. *Figure 11* shows how the relationships of these three physical parameters are manifested in the final CPP administrative map. The disagreement in western Mali and some divergent results in southern Mali appear to be caused by the same phenomena. The CPP model also classifies more land near Mopti and in the dryer regions as potentially suitable for cotton. Again these differences are most likely due to the emphasis put on potential irrigation areas in the north. Despite the disagreements, the models found significant agreement in the unsuitable lands of northern Mali and in the Niger River areas.

Remarkable about the case of Benin is that the country scored quite badly in economic parameters and, conversely, quite well for human parameter scores. This result gives reason to examine not only how parameters were heuristically organized and operationalized, but also why economic conditions in this country are not commensurate with human parameters. Perhaps one reason is that the economic parameters contain variables more specific to cotton production. In contrast to Burkina Faso, Benin scored particularly low in the producer price related variables, indicating an unstable institutional setting. Like other countries in the region, Benin has been going through a liberalization process of its cotton sector. But this process has been less than smooth following the beginning of privatization of certain activities of SONAPRA, the public entity in Benin's cotton sector. While the vertically integrated SONAPRA entity had previously ensured the distribution of inputs, access to credit, and provision of public services, the structure which is evolving as a result of the reforms of the cotton sector is much more splintered. Unlike Burkina Faso, where producer groups are actively engaged in the management of the cotton sector, splits have emerged among the producers' groups in Benin following the reforms. There has been a steady rise in non-compliance or delays in meeting obligations in payments, loan servicing and delivery of services, resulting in a dangerous erosion of confidence in the system [9]. In a production system that relies on a basic level of trust in the functioning of institutions, such an erosion of confidence can have detrimental effects on the overall cotton production potential [9]. While the CPP model indicates that Benin has sound physical and human capital, the unstable variables of its economic parameters caused by the institutional malfunction suggest that cotton production potential could be much higher. The results of Benin underscore the importance of an interdisciplinary approach to the analysis of cotton production.

Sustainability and Policy

The questions that these findings raise in regard to cotton policy are closely linked to sustainability. Cotton production is intimately linked with questions of sustainable land use and human-environment systems in SSA. For example, much of the increased production of cotton in recent years in Africa comes from land expansion [11], often disregarding ecological considerations [1]. There are other options besides land expansion, but these all ultimately implicate sustainability as well: increased use of fertilizers and pesticides; GM cotton experimentation in Burkina Faso; and new seeds from China. However, it is sure that land expansion according to rainfall will remain the main vehicles of increased production for the regions' small farmers in the near if not long term future.

The CPP model has at least two functions in informing sustainable policy decisions. The first is to examine ongoing trends in production compared to potential trends in production in order to understand constraints to ecologically and socially sustainable production relations. In this case, administrative districts in south-central Burkina Faso and southern Mali that express high potential but low actual production could be investigated. Although the model cannot predict particulars on how sustainable policies will unfold in certain administrative districts, it can identify districts where production potential is limited by constraints. The second way in which the CPP model can be used to inform and shape sustainable policy is by using it to run scenarios. For example, one could project cotton production potential under varying conditions of precipitation (e.g. simulating drought). Perhaps most intriguingly, one could simulate the effect that a higher world price of cotton would have on production levels over the entire region or in particular areas [8]. At this point, scenario simulations are limited to leveraging one variable. However, establishing more dynamic relationships between the parameters would allow complex, georeferenced simulations of cotton growth. If areas with high production potential are identified early, appropriate policy measures can be taken to ensure that the particular environmental situation in these areas is taken into consideration.

5 Conclusions

By applying the CPP model to Mali, Benin, and Burkina Faso we find spatially-referenced trends that indicate where cotton can be grown and what might be constraining cotton production in the region. Although the model does offer interesting discussion points and potentially serves as a tool to support sustainable practices in cotton production in the region, it will require more work. One of the basic advantages of this model is that it is georeferenced. However, the model needs validation. Ground truth data acquisition in the region would accomplish the goal of validation as well as offering the model a way of using historical data from known points to build dynamic relationships between parameters. Postulated dynamic relationships (whether causal or correlation) are necessary for scenario modeling. As well, understanding the relationships between parameters is key to creating a parsimonious model that can eliminate collinearity. Ground truth points also offer more reliable and localized data, overcoming many problems with unreliable data, anachronism, and scale. Specifically, this need is manifest for economic parameters. Most economic parameters are available only at a national level.

The policy relevance of this model is obvious, offering a transparent method of valuating policy for meeting sustainable goals, such as those of the *Millennium Ecosystem Assessment* [19], in the particular context of cotton production in the poorest continent in the world. Moreover, this model is an attempt to improve the understanding of the spatial components of cotton – which affects millions of livelihoods in the region – so as to provide a tool to make policy decisions effective and more relevant to people on the ground. We hope to advance this model to its next stages through ground truth acquisition and reconfiguration of parameters in order to offer a viable way to improve cotton production.

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