RESEARCH HIGHLIGHTS

CLIMATE CHANGE AND FUTURE CROP SUITABILITY IN MALAWI

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Research Highlights – Climate Change and Future Crop Suitability in Malawi

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RESEARCH HIGHLIGHTS

CLIMATE CHANGE AND FUTURE CROP SUITABILITY IN MALAWI

BACKGROUND AND CONTEXT

The Adaptation for Smallholder Agriculture Programme (ASAP) is a flagship programme within the International Fund for Agricultural Development's (IFAD's) portfolio of activities aimed at channelling climate and environmental finance to smallholder farmers, and which allows IFAD country programmes to design projects which integrate considerations of the impacts of climate change on smallholder farmers. To support the integration of climate information and improved knowledge of climate related risks to the smallholder agriculture sector, IFAD commissioned a Climate Risk Analysis to assess the potential impacts of climate change on several crops and commodities in Malawi.

The full Climate Risk Analysis report (accessible via the IFAD Country page[1] provides an analysis of inter alia i) the current and future climate characteristics of Malawi; ii) the potential change in the suitability of various crops under projected climate changes; and iii) potential risks and economic impacts related to climate change, as well as potential adaptation options and opportunities to increase climate resilience. The following report provides a brief summary of highlighted results for Malawi, including: i) projected changes to temperature and precipitation as a result of climate change; and ii) impacts of climate change on the future suitability of several major crops and resulting impacts on production across each of the country's eight Agricultural Development District (ADD) regions.

AGRICULTURE IN MALAWI

Malawi's agricultural production is characterised by moderately low productivity of a wide selection of staple crops, a diverse variety of annual and perennial horticultural products, and cash crops (most prominently, tobacco). Rainfed agriculture, practiced by smallholder farmers, accounts for the vast majority of the planted area. In addition to rainfed production of staple crops, there are complex mixed farming practices that include various fruit trees adjacent to households (bananas, avocado, mango, pawpaws and citrus) and mixed kitchen-scale gardens for production of diverse vegetable species, and grazed production of cattle and small ruminant livestock.

1 https://www.ifad.org/en/web/operations/country/id/Malawi

SUMMARY RESULTS

The likely effects of climate change are not fully consistent between each of Malawi's three regions and 28 districts, or the crops assessed. However, several general observations can be made. For example, all districts in the study area are predicted to experience increasing temperatures throughout the year, indicated by increased average monthly 'Mean Temperature' as well as average 'Minimum Temperature'. Furthermore, all districts are predicted to experience increasing delays or inconsistencies in the onset of rainfall, and an overall decrease in the annual and seasonal precipitation between the present day and the 'Mid-Century' future (defined by the period ~2040–2069).

The full study includes detailed descriptions of the predicted effect of climate change on various staple and cash crops including inter alia cereals (maize, sorghum), legumes (beans, cowpeas, pigeonpeas and groundnuts), and root crops (cassava), in each of Malawi's eight ADDs. In addition, the supplementary annexes contain additional analyses of the likely climate change effects on other crops at the national level, including cereals (rice, finger millet and pearl millet), oil crops (soyabeans, sunflowers), root crops (irish potato and sweet potato) and assorted horticultural and cash crops (bananas, cashews, cotton, tomatoes).

The combined effects of reduced precipitation and increased temperatures are likely to result in a complex matrix of positive and negative effects on the crops assessed. The annual production of certain climate-sensitive crops, notably including beans and maize, is expected to be negatively impacted by increased temperatures and reduced or delayed rainfall, thereby causing a reduction in the extent of suitable production areas as well as reducing the productivity of remaining areas across the country. Conversely, certain climate-resilient species such as cowpeas, groundnuts, sorghum and millet are comparatively less affected by the predicted climate changes, and may be appropriate alternative staples to be promoted in areas where maize production is expected to become marginal or unsustainable.

However, despite these common trends, there are also several district-specific effects on climate variables and resultant crop suitability that will necessitate the development of tailored local-level adaptation plans and strategies for agricultural development. For example, the staple cassava crop is predicted to undergo negative changes in the southern and central regions but may benefit from increased suitable areas and productivity in the northern regions. Similarly, other crops such as groundnuts may benefit from a mix of positive, negative and neutral effects between each ADD.

The climate-related risks to agricultural households in each district are a function of both the impact of climate change on crop production, as well as the adaptive capacities of each community to manage and respond to climate risks. This study found that smallholder farmers in the Mzuzu, Blantyre and Lilongwe ADDs have the highest overall capacities to respond to climate change's impacts (i.e. the latter three ADD regions have the greatest capacity to respond and adapt to climate change impacts). The Machinga, Salima and Shire Valley ADDs have the lowest overall AC scores and therefore are anticipated to be least able to respond or adapt to climate change-related impacts

It is important to note that the following analyses are based on consideration of a narrow range of modelled variables and the resultant effects on crop suitability. Consequently, this study cannot account for local-level factors such as differences in performance, climatic suitability and yield potential between local land races or improved cultivars. In addition, the study cannot consider or predict the effect of different cultivation methods and technologies that may be practiced within the study area. Finally, in terms of predicting the likely effects of climate change and resultant risks to crop production, this study cannot account for indirect effects of climate change on crop production, such as increased vulnerability to pests and disease, soil degradation or flooding/waterlogging. However, the study does find that climate change is likely to result in multiple negative effects on smallholder farmers in the study area, through disruption of familiar seasonal trends, increased water and heat stress and reduced growing season.

METHOD AND APPROACH

The analyses presented in this study are intended to provide an illustrative comparison of the potential effects of future climate change on production of economically important crops, as well as the differential impacts of climate change on agricultural households in each of Malawi's eight Agricultural Development District (ADD) regions. For each of the crops considered in this study (beans, cassava, cowpeas, groundnuts, maize, pigeonpeas and sorghum) the relative ***Climate Change Vulnerability (V)*** of crop production is considered at the district level and aims to identify those ADD regions which are likely to be most or least vulnerable to climate change impacts on the given crop. The relative vulnerabilities of each district can be expressed as a **Vulnerability Index (VI)** score, derived by comparison of the relative scale of:

- **Impacts (I)** of climate change on crop production (estimated through analysis of climate models and resulting changes to crop suitability); and
- the **Adaptive Capacity (AC)** of agricultural households to respond and adapt to the impacts of climate change (derived through statistical indicators of socio-economic, developmental and agronomic context);

in each of Malawi's eight Agricultural Development District (ADD) regions. **Vulnerability** is considered to be proportional to the relative size of I, and inversely proportional to **AC**. The product of the scores for **AC** and **I** are used to calculate a standardised score for **V**, thereby allowing comparisons between each district and allowing the identification of those districts and households which are likely to be most vulnerable to climate change impacts on each crop.

IMPACTS

The **Impacts (I)** of climate change on crops were estimated by projecting the likely future changes to Malawi's climate, and then analysing the effects of those projected climate changes on economically important crops. Firstly, the potential future changes to Malawi's climate were computed through analysis of 29 General Circulation Models (GCMs) downloaded from the AgMERRA dataset [2], based on the methods described by Ramirez-Villegas et al (2013) [3]. Future climate changes were computed assuming the scenario of 'RCP 8.5' (where 'RCP 8.5' refers to one of four hypothetical scenarios for future global greenhouse gas emissions proposed by the Intergovernmental Panel on Climate Change). This analysis was used to generate predictions of the effect of climate change across Malawi, comparing the historical baseline (the average climate for the period 1980–2010) to the Mid-Century future (2050, the average climate for the period 2040–2069). In particular, the analysis compares the climatic variables of *Mean Monthly Precipitation* (i.e. the average precipitation for each month), *Monthly Mean Temperature* and *Monthly Minimum Temperature* (Tmin).

Analyses of current and future crop suitability were generated using the Food and Agriculture Organisation's EcoCrop Suitability model [4] combined with the most recent statistics available for annual crop production and demographics. The EcoCrop model estimates the suitability of a given crop to the defined environmental conditions based on the known preferences of each crop such as: i) minimum, optimum and maximum temperature; ii) minimum, optimum and maximum monthly rainfall; and iii) minimum and maximum growing period. Therefore, EcoCrop defines the area of suitability for a given crop based on whether there are adequate climatic conditions (temperature and precipitation) within the growing season and calculates the climatic suitability of the resulting interaction between rainfall and temperature. Readers are referred to the full project report and the work of Ramirez-Villegas et al (2013) for detailed description of methodology.

A suitability index score, ranging from 0 – 1, indicates the relative suitability of a given area for each of the crops assessed (where a

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2 https://data.giss.nasa.gov/impacts/agmipcf/agmerra/

3 Ramirez-Villegas J, Jarvis A, Laderach P 2013 Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. Agricultural and Forest Meteorology 170(15):67-78

4 https://ecocrop.fao.org/ecocrop/srv/en/home

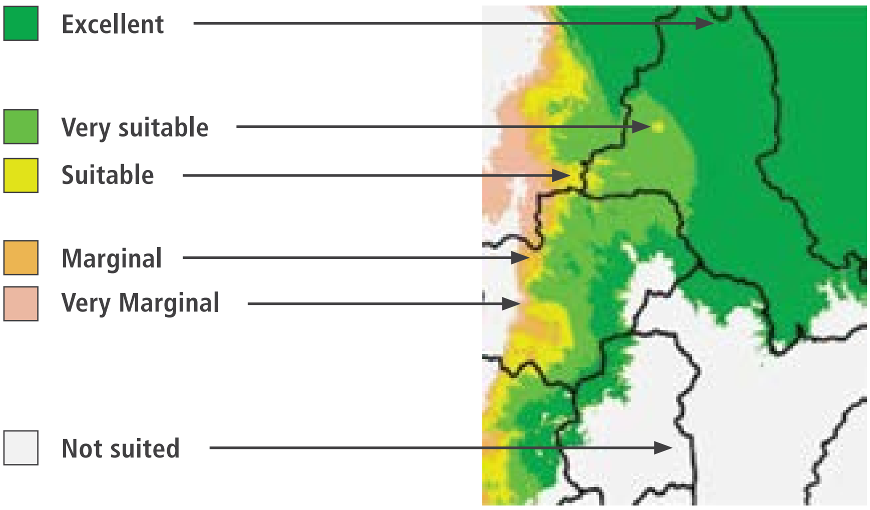
suitability score of 0 is considered to be totally unsuitable, a score of 1 is considered excellent, with a continuous spectrum of marginal, moderate and good suitability types in between). In this study, analyses of the distribution of suitable areas for a given crop allows for the estimation of the total suitable production area, as well as the average suitability index score, within each of Malawi's eight Agricultural Development District (ADD) regions. The EcoCrop approach also allows for map-based visualisations of crop suitability zones across the country. The use of colour-coded maps to depict the distribution of various categories of crop suitability index scores can be used to demonstrate the distribution of crop-suitable areas, as demonstrated in Figure 1.

The comparison of maps of 'Historical' and 'Future' distribution of crop suitability can be used to estimate the potential changes to the size and relative productivity of crop-suitable areas. In addition, this approach allows for the identification of specific areas which are likely to undergo positive or negative changes (anomalies) as a result of climate change, and may be used to inform decision-making such as identification of climate-vulnerable areas and value chains to be prioritised for additional support. The potential impacts of climate change on each crop were estimated based on: the changes to total suitable area (km2) and average suitability index score between the historical baseline and 'mid-century' future [5]; and estimated historical crop production in each District, derived from national agricultural production statistics [6].

The potential impacts of climate change on each crop can be quantified in several ways, for example, in terms of changes to "production per capita", "production per household" and "production per District". It should be emphasised that no further calibration or validation of EcoCrop analyses was carried out in support of this study and that results should be considered as indicative guidelines only, to inform additional local-level decision-making and further research.

FIGURE 1. DEMONSTRATION EXAMPLE OF THE DISTRIBUTION OF CROP SUITABILITY INDEX.

GENERATED USING ECOCROP



[5] Total suitable area was calculated as the sum of all areas with a suitability index score higher than 0, and average suitability index score is calculated as the average score of all areas with a suitability index score higher than 0

[6] Derived from the most recent statistics published in the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office, http://www.nsomalawi.mw/images/stories/data_on_line/economics/ihs/IHS4/IHS4%20REPORT.pdf

ADAPTIVE CAPACITY

Indicators for **Adaptive Capacity (AC)** – the relative ability of agricultural households to respond and adapt to predicted climate change impacts – were derived from the most recent statistics available at the sub-national level [7]. In the case of Malawi, the indicators used to estimate AC in each district included

- **Education** % literacy rate;
- **Access to alternative (non-agricultural) income:** households operating a non-agricultural enterprise, households reporting adequate food;
- **Adoption of improved agricultural practices:** fertiliser use among small-holder farmers, manure use, herbicide use;
- **Access to agricultural information:** agricultural households with a cellular phone; and
- **Access to financial services:** households that obtained a loan.

Figures are derived from the most recent statistics published in the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office[8].

The national statistics collected to assess AC – which are summarised in the Appendix (Table A.1) – were used to calculate an average AC score for each District. The indicator category **'Adoption of improved agricultural practices'** was assigned a weighting of 50% towards the final **AC** score, and the remaining 50% was contributed equally by the remaining indicator categories. These are presented in Table 1.

The **AC** scores generated indicate that smallholder farmers in the Mzuzu, Blantyre and Lilongwe ADDs have the highest overall capacities to respond to climate change's impacts (ranking 1st, 2nd and 3rd, respectively). The Machinga, Salima and Shire Valley ADDs have the lowest overall **AC** scores (ranking 6th, 7th and 8th, respectively) and therefore are anticipated to be least able to respond or adapt to climate change-related impacts.

TABLE 1. RANKED ADAPTIVE CAPACITY (AC) INDICATOR SCORES FOR ALL ADD REGIONS OF MALAWI

	Adaptive capacity Indicator category						
	Adoption of improved agricultural practices	Access to alternative income	Access to agricultural information	Education	Access to financial services	**Adaptive capacity score**	**Adaptive capacity rank**
Contribution to index	50%	12.50%	12.50%	12.50%	12.50%		
Blantyre	29	29	48	11.5	76	35.1	**2**
Karonga	20	30	52	7.3	81	31.2	**5**
Kasungu	26	23	47	14.3	73	32.6	**4**
Lilongwe	29	30	48	12.6	73	34.9	**3**
Machinga	26	20	43	9.3	66	30.4	**6**
Mzuzu	31	32	72	20.6	87	42	**1**
Salima	20	19	45	16.1	65	28	**7**
Shire Valley	8	29	34	13.1	59	21.3	**8**

7 Derived from the most recent statistics published in the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office, http://www.nsomalawi.mw/images/stories/data_on_line/economics/ihs/IHS4/IHS4%20REPORT.pdf

8 ibid

CLIMATE PROJECTIONS

PROJECTED CHANGES TO TEMPERATURE IN MALAWI BY 2050

The predicted changes in TMean during the period from 'Historical' to 'Future, 2050' timepoints indicate that climate change will result in consistent increases in Mean Temperature across spatial and temporal dimensions in Malawi. A common prediction across each of the country's districts is that TMean will increase in all districts during the period from 'Historical' to 'Future 2050' timepoints by at least 1.8°C. The hottest months of October, November and December are predicted to increase by 2.1–2.5°C, relative to a Historical average of 27–28.4°C. Similar increases of 1.8–2°C are predicted for all other months of the year, including the peak summer months that support the rainfed agricultural season (up until March/April) as well as the colder winter months of May–August.

The overall effect of these increases in TMean is likely to result in complex impacts on the agricultural sector, particularly when considered in combination with the predicted decreases and delayed timing of precipitation. The large increases in temperature (2.1–2.5°C) in the months of October–December will increase crop water demand and evapotranspiration losses of water from agricultural soils, coinciding with the reduced rainfall predicted for the same months. This effect is likely to increase the risks of crop failure as a result of inadequate or erratic rainfall during the establishment of rainfed crops. Furthermore, the increased average temperatures are likely to include increased frequency or severity of heat waves and unusually hot days, further contributing to evapotranspirative losses of water and crop stress.

A possible additional effect of the increase in temperatures during the winter months may be to increase the feasibility and productivity of irrigated agriculture during the dry, cooler winter months (particularly in low-lying river basin areas and adjacent to Lake Malawi where irrigation may be feasible). Increased winter temperatures may result in suitably warm conditions for off-season irrigated production of staples such as maize and beans, as well as various horticultural crops such as tomatoes, peppers, and other assorted vegetables.

Taken cumulatively over the entire growing season, the combination of reduced rainfall and increased temperature is likely to reduce agricultural production, either as a result of decreased yield or outright crop failure, particularly in the case of heat- and drought-sensitive crops such as maize and wheat. However, the magnitude of this effect is likely to vary between and within each district according to the spatial distribution of rainfall as well as anomalies in temperature.

TABLE 2. PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY TEMPERATURE (°C) IN MALAWI AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS [9]

Tmean (°C)	**MONTH**											
	J	F	M	A	M	J	J	A	S	O	N	D
Historical	24.0	24.0	24.0	23.1	21.5	19.6	19.2	20.6	23.2	25.2	25.9	24.8
Future	25.8	25.7	25.8	25.0	23.5	21.6	21.2	22.6	25.1	27.3	28.4	27.0
Anomaly	**1.8**	**1.8**	**1.9**	**1.9**	**2.0**	**2.0**	**2.0**	**1.9**	**1.9**	**2.1**	**2.5**	**2.2**

[9] Historical temperature based on the average of the period 1980-2010, and projected Mid-Century temperature for the period 2040-2069. Anomalies are defined as the total change between Historical and Mid-Century projections

CLIMATE – PROJECTED CHANGES TO RAINFALL IN MALAWI BY 2050

The predicted changes in mean monthly precipitation from the historical baseline to the mid-century (2050) future indicate that climate change will result in complex changes in rainfall across ADD regions and months. (see Table 3, below). District-level summaries of predicted monthly changes in precipitation can be found in the supplementary Appendix.

A common prediction across each of the country's districts is that total annual precipitation will be reduced in all districts during the period from 'baseline' to 'Future 2050' timepoints. Total rainfall at the onset of the rainy season in the months of November and December is predicted to be reduced from 66 to 42 mm/month and 194 to 171 mm/month (total reduction of rainfall of 24 mm and 23 mm, respectively). Further reductions in monthly precipitation are predicted for the mid-summer rainy season months from January–March ranging from 10 to 14 mm/month. The overall effect of these reductions to monthly precipitation throughout the rainy season is to reduce the total seasonal rainfall for the period October–April by 10.5 %, from ~980 mm/season to 877 mm/season.

An additional effect, which is likely to vary on an interannual basis as well as spatially within each season, is the effective timing of the onset of rainfall at the start of the growing season. The average reduction in national rainfall predicted for the start of the rainy season is likely to vary between districts and Malawi's agro-ecological zones but in some cases may result in inadequate rainfall to support effective establishment of crops during the period which is traditionally associated with the start of the growing season.

These analyses indicate that climate change may delay the onset of rainfall relative to the traditional agricultural calendar, in turn resulting in changes to the timing of various agricultural activities such as field preparation and sowing of seed. The majority of the rainfed agricultural growing season is characterised by monthly rainfall deficits and is likely to result in fundamental changes to local crop choices and agricultural practices by the year 2050.

TABLE 3. PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY PRECIPITATION (MM/MONTH) IN MALAWI AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS [10].

MM/MONTH	MONTH												TOTAL
	J	F	M	A	M	J	J	A	S	O	N	D	
Historical	235.2	203.2	186.3	80.0	16.7	8.3	7.6	4.8	4.7	14.2	66.2	194.3	1021.5
Future	222.2	193.7	172.5	67.7	12.1	5.5	5.1	3.4	2.4	7.1	42.4	171.3	905.4
Anomaly	**-13.1**	**-9.5**	**-13.8**	**-12.3**	**-4.6**	**-2.9**	**-2.5**	**-1.4**	**-2.3**	**-7.1**	**-23.8**	**-23.0**	**116.1**

10 Historical precipitation based on the average of the period 1980-2010, and projected Mid-Century precipitation for the period 2040-2069. Anomalies are defined as the total change between Historical and Mid-Century projections. District-level summaries of predicted monthly changes in precipitation can be found in the supplementary Appendix).

CLIMATE CHANGE AND ITS EFFECT ON BEANS

BROAD CONTEXT

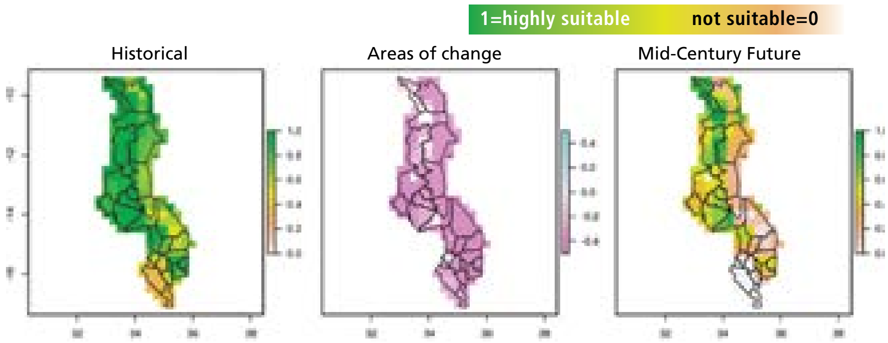
Beans are widely grown as a staple subsistence crop across all of Malawi's ADD regions, with widespread areas of marginal or moderate suitability.

All regions are projected to experience decreases to average suitability index score. The ADDs worst affected are likely to include Machinga (52%), Blantyre (45%), Salima (31%) and Shire Valley (33%), where the future suitability scores are projected to be reduced to marginal or very marginal. Furthermore, the areas of Blantyre and Shire Valley are anticipated to undergo decreases to the overall suitable area, and will therefore be affected both by a decrease in production area as well as a decrease in the productivity of those remaining suitable areas. In the case of Shire Valley, the projected decreases to suitable area (90%) and suitability score (33%) are too large to be credible – however, these are likely to indicate that future production is highly marginal or tending towards totally unsuitable.

PRODUCTION OF BEANS IN MALAWI[11].

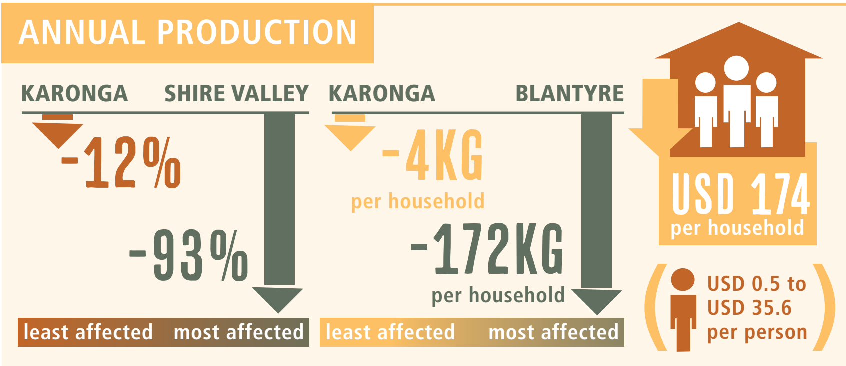
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	54,231	26.6	90,554	47.4
Karonga	6,051	3.0	5,295	2.8
Kasungu	39,710	19.5	29,813	15.6
Lilongwe	42,649	20.9	25,445	13.3
Machinga	25,885	12.7	17,136	9.0
Mzuzu	23,642	11.6	13,879	7.3
Salima	1,549	0.8	1,162	0.6
Shire Valley	10,053	4.9	7,780	4.1
Total	**203,770**		**191,063**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR BEANS IN MALAWI



HOUSEHOLD LEVEL IMPACTS

In terms of %change production per household, it is predicted that households will experience a decrease in annual production ranging from -12% in Karonga, up to -93% in Shire Valley. In the latter case, the projected decrease in suitability and resultant productivity should not be interpreted as an absolute loss of all production, but more likely indicates that the Shire Valley ADD will become highly marginal and vulnerable to substantial decreases in annual production. In addition to the latter ADD, it is projected that Salima, Machinga and Blantyre will experience the greatest negative changes (reductions of 31%, 52% and 61%, respectively) to %production at the household level.



In terms of the total impact of climate change on the annual production of agricultural households, the predicted decrease in annual production may range from 4 kg up to 172 kg per household. The ADD regions anticipated to be most negatively impacted by total reduced production at the household level include Kasungu, Machinga and Blantyre ADDs (48, 51 and 172 kg per household per annum).

The costs of reduced production of beans are estimated to range from USD 0.5 to 35.6 per person, or, up to USD 174 per household[12].

[11] Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

[12] US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for beans varies between districts – average price across all districts was approximately USD 1.0 per kg

DISTRICT AND NATIONAL-LEVEL IMPACTS

At the ADD level, the total reduction in annual production of beans is projected to range from 361 tonnes in Salima, the least affected ADD, to 55,000 tonnes in Blantyre. In total, it is estimated that the annual production of beans across all ADDs will be reduced by 90 000 tonnes.

It is anticipated that Blantyre (USD 56.2 million), Machinga (USD 9.9 million) and Kasungu (USD 9.1 million) will incur the greatest costs for purchase of replacement food. At a national scale, the total annual cost of climate-related impacts on beans is estimated to be USD 91.5 million per year.

Total loss of annual production
90 000 tonnes

Total annual cost
USD 91.5 million

CLIMATE VULNERABLE ADDS AND HOUSEHOLDS

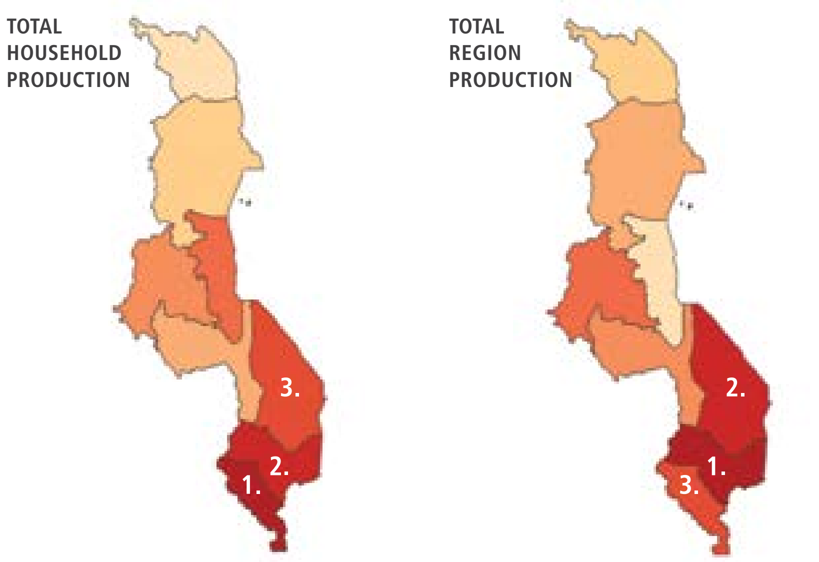
At the household level, the districts which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Blantyre (2) and Machinga (3).

At the ADD level, the most severe negative impacts on total production per ADD region are Blantyre (1), Machinga (2) and Shire Valley (3).

Most vulnerable

Least vulnerable

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

Moderate decrease in area and productivity in all ADDs (Blantyre, Machinga and Shire Valley are likely to be particularly vulnerable).

The cumulative loss of production of beans across all ADDs is equivalent to 90,000 tonnes per annum and is likely to result in considerable increased costs for households to replace the lost production of staple food, as well as an increase in the demand for imported beans and alternative legumes (estimated replacement costs for lost production is estimated to be USD 91.5 million per year).

Despite the predicted negative changes to production, it is likely that beans will be comparatively more resilient than crops such as maize. Beans, and other leguminous crops, will therefore remain a useful option for climate-resilient farming systems.

Require sustained efforts of research and development to identify the most locally appropriate cultivar, and to address weak and underdeveloped value chain for legume crops.

CLIMATE CHANGE AND ITS EFFECT ON CASSAVA

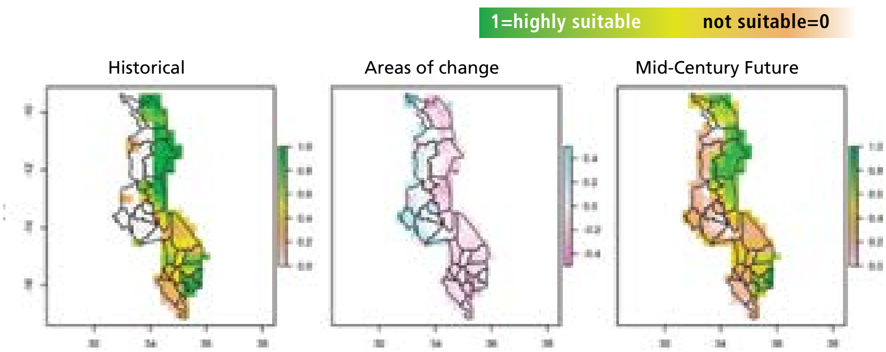
BROAD CONTEXT

Cassava is widely grown as a staple subsistence crop across all of Malawi's ADD regions, with widespread areas of marginal or moderate suitability, and narrow extents of good suitability in the north-eastern districts bordering the lake. All ADDs are expected to experience complex negative and positive changes to suitability for cultivation of cassava. All regions are projected to experience decreases to average suitability index score, ranging from -14% to -44%. The ADDs worst affected are likely to include Kasungu (44%), Shire Valley (-39%) and Lilongwe (-31%). Simultaneously, despite the decrease in average suitability index score, several ADDs may benefit from increased suitable production areas, including Karonga, Kasungu, Lilongwe and Mzuzu (although the latter areas are likely to be only marginally suitable).

PRODUCTION OF CASSAVA IN MALAWI[13].

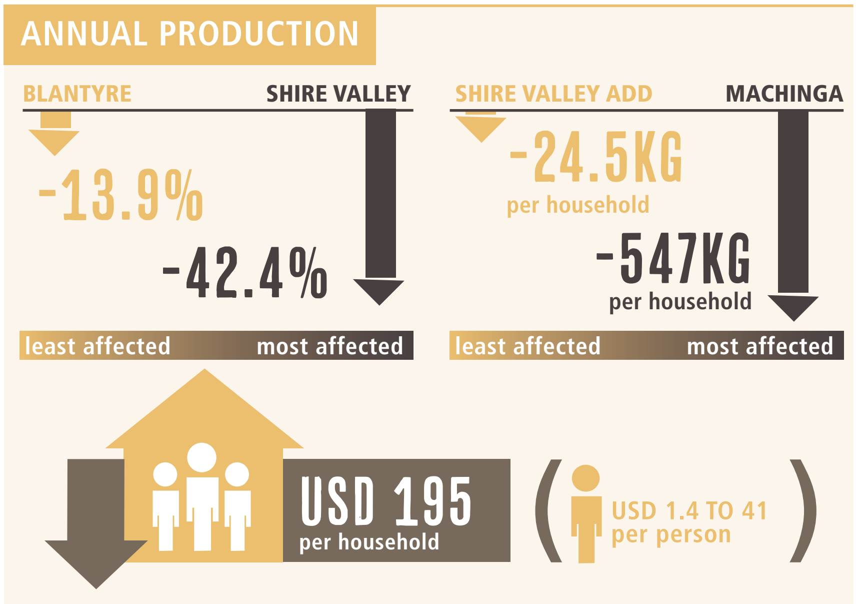
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	42,486	18.0	1,065,287	19.9
Karonga	24,655	10.5	624,836	11.7
Kasungu	30,853	13.1	779,363	14.6
Lilongwe	21,843	9.3	411,154	7.7
Machinga	32,131	13.6	431,154	8.1
Mzuzu	46,000	19.5	1,110,161	20.7
Salima	36,623	15.5	917,646	17.1
Shire Valley	967	0.4	15,225	0.3
Total	**235,558**		**5,354,826**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR CASSAVA IN MALAWI



HOUSEHOLD LEVEL IMPACTS

In terms of %change production of cassava per household, it is predicted that households in Blantyre, Machinga and Shire Valley will experience a decrease in annual production ranging from -13.9% in Blantyre up to -42.4% in Shire Valley. However, the latter region is not a major producer of cassava, and consequently this decrease of 42% is only equivalent to an annual deficit of 24.5 kg per household or a total of 6,460 tonnes for the entire Shire Valley ADD. However, in Blantyre and Machinga, the annual deficit of cassava production is equivalent to 460 kg and 547 kg per household, respectively. In those ADDs which are projected to experience negative impacts on cassava production, the costs of reduced production are estimated to range from USD 1.4 up to USD 41 per person, or, up to USD 195 per household.



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[13] Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

DISTRICT AND NATIONAL-LEVEL IMPACTS

At the ADD level, the Blantyre and Machinga ADDs may experience an annual deficit in cassava production of 148,000 and 164,000 tonnes, respectively. In total, it is estimated that the annual production of cassava across Blantyre, Machinga and Shire Valley will be reduced by 218,000 tonnes. It is possible that the increased suitable areas in the remaining five ADD regions will result in net positive effects on the annual production of cassava. However, these results cannot support that assumption and consequently these potential positive impacts are not included in the final estimation of changes to annual production. At the ADD scale, it is anticipated that the total costs for purchase of replacement food will be approximately USD 59.6 million in Blantyre, USD 22.7 million in Machinga and USD 1.85 million in Shire Valley. At a national scale, the total annual cost of climate-related impacts on cassava is estimated to be USD 84.2 million per year[14].

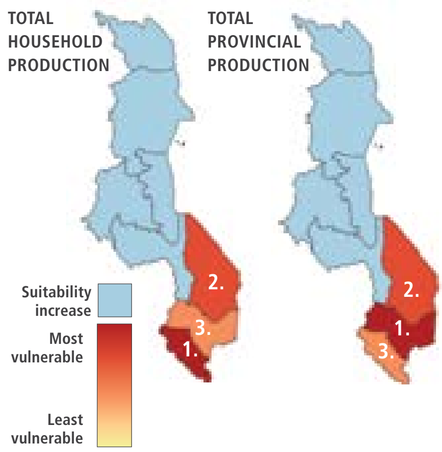
Total annual cost USD 84.2 million

CLIMATE VULNERABLE ADDS AND HOUSEHOLDS

As described previously, Karonga, Kasungu, Lilongwe and Salima may benefit from increased suitable areas for cassava production. Although it cannot be inferred that these areas will benefit from increased annual production, the results suggest that these latter regions are unlikely to experience severe climate change-related impacts to production of cassava. In terms of the ADDs that are likely to be most vulnerable to climate change impacts on production of cassava:

- At the household level, the ADDs which will experience the most severe impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Machinga (2) and Blantyre (3).
- At the ADD level, the most severe impacts on total production per administrative region are Blantyre (1), Machinga (2) and Shire Valley (3).

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

Several ADDs (Karonga, Kasungu, Lilongwe and Salima) may benefit from increased production area of cassava during October to December as a result of climate change.

The remaining ADD regions (Blantyre, Machinga, Shire Valley) are likely to experience negative impacts on production of cassava.

Moderate decrease in area and productivity across all ADDs (Blantyre, Machinga and Shire Valley are likely to be particularly vulnerable).

The cumulative loss of production of Cassava across all ADDs is equivalent to 218,000 tonnes per annum and is likely to result in annual replacement costs for lost production of USD 84.2 million per year).

Despite the predicted negative changes to production, cassava remains a useful option for climate-resilient farming systems (flexible harvest period, drought-tolerant, widely grown and accessible).

Recommended actions: increased access to quality, virus-free planting material of improved varieties; increased access to facilities and equipment for processing fresh cassava; improved capacity of farmers to monitor and respond to common pests and diseases.

[14] US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for cassava varies between districts – average price across all districts was approximately USD 0.3 per kg

CLIMATE CHANGE AND ITS EFFECT ON COWPEA

BROAD CONTEXT

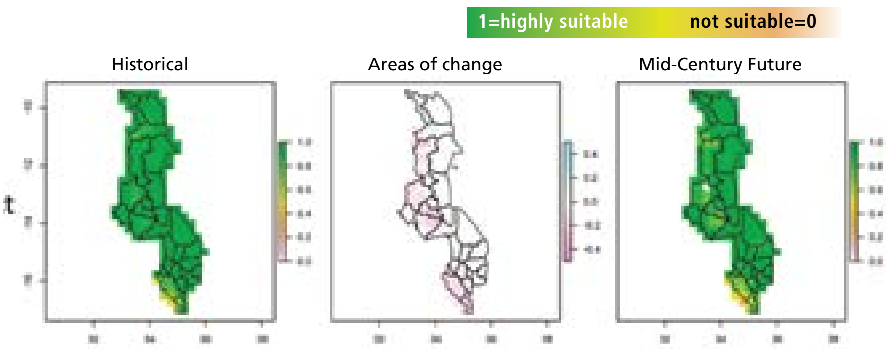
Cowpeas are widely grown as a staple subsistence crop across all of Malawi's ADD regions, where the entire extent of the country appears to be suitable for cowpea production.

All ADD regions are expected to experience very minor negative changes to suitability for cultivation of cowpeas. Small negative changes to the average suitability index score, and resultant productivity are expected. However, despite the small decrease in productivity, all ADD regions are projected to remain highly suitable or excellent for cowpeas with the exception of Shire Valley. In the latter case, Shire Valley is projected to undergo a ~7.5% decrease of productivity but is still likely to be characterised by good suitability.

PRODUCTION OF COWPEA IN MALAWI[15].

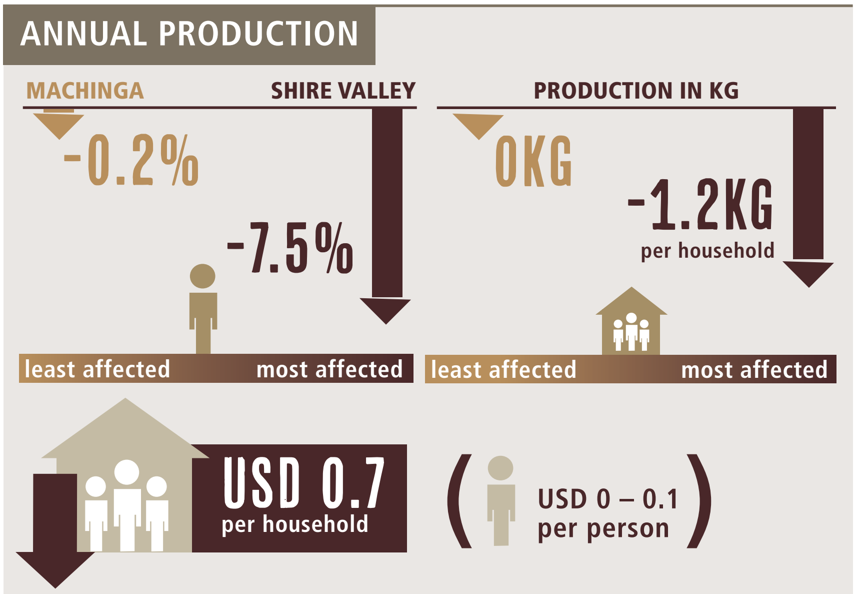
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	19,312	26.6	19,312	26.6
Karonga	2,155	3.0	2,155	3.0
Kasungu	14,142	19.5	14,142	19.5
Lilongwe	15,188	20.9	15,188	20.9
Machinga	9,218	12.7	9,218	12.7
Mzuzu	8,419	11.6	8,420	11.6
Salima	552	0.8	552	0.8
Shire Valley	3,580	4.9	3,580	4.9
Total	**72,566**		**72,567**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR COWPEA IN MALAWI



HOUSEHOLD LEVEL IMPACTS

Most ADD regions are predicted to experience very minor negative impacts on cowpea production. In terms of %change production of cowpeas per capita, it is predicted that households will experience a decrease in annual production ranging from -0.2% in Machinga up to -7.5% in Shire Valley. Even in the most negatively affected regions, the total annual change in production is equivalent to 1.2 kg of lost crop production per household. The costs of reduced production of cowpeas are estimated to range from USD 0 to 0.1 per person, or, up to USD 0.7 per household[16].



[15] Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

[16] US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for cowpeas varies between districts – average price across all districts was approximately USD 0.6 per kg

DISTRICT AND NATIONAL-LEVEL IMPACTS

At the ADD level, the deficit in total production of cowpeas may be as little as 1 tonne (in Salima), up to 387 tonnes (in Blantyre). Karonga is the only region which is predicted to benefit from slight increases in production, as a result of the increase in average suitability score.

In total, the cumulative loss of production of cowpeas across all ADD regions is equivalent to 994 tonnes, not including consideration of the possible increased production as a result of increased suitability in Karonga. At the ADD scale, it is anticipated that the greatest costs for purchase of replacement food will include Blantyre (USD 216,000), Kasungu (USD 106,000) and Shire Valley (USD 89,000) regions. At a national scale, the total annual cost of climate-related impacts on cowpeas is estimated to be USD 507,000 per year.

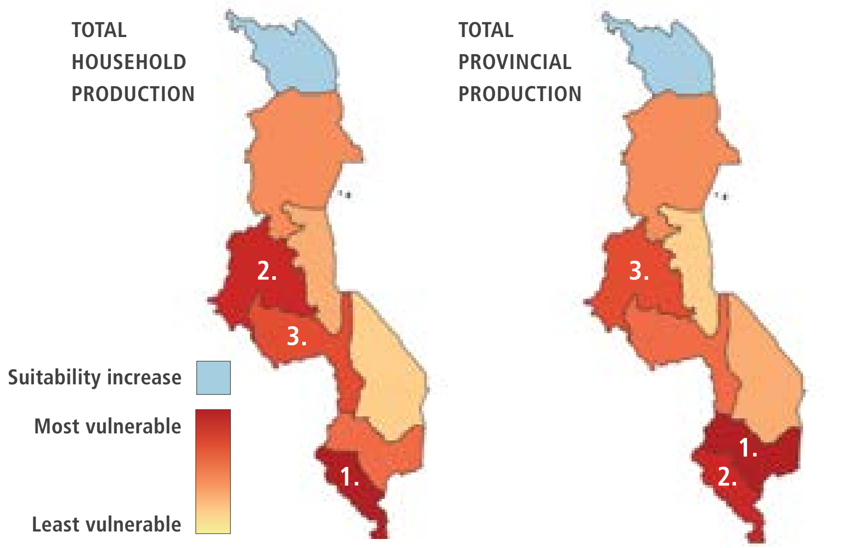
Total annual cost USD 507 000

CLIMATE VULNERABLE ADDS AND HOUSEHOLDS

At the household level, the ADDs which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Kasungu (2) and Lilongwe (3)

At the ADD level, the most severe negative impacts on total production per administrative region are Blantyre (1), Shire Valley (2) and Kasungu (3).

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

The cumulative loss of production of cowpeas across all ADDs is estimated to be 994 tonnes per annum, equivalent to a decrease in household production ranging from 0.2 – 1.1 kg.

Total replacement costs related to the deficit of annual food production are estimated to be USD 507,000 per year.

Despite the predicted negative changes to production, it is likely that cowpeas will be comparatively more resilient than many other crops and will therefore remain a useful option for climate-resilient farming systems (e.g. as an alternative or a complement to other legume or cereal crops which are poorly adapted to erratic or irregular rainfall and increased temperatures).

Highly compatible with Conservation Agriculture approaches and suitable as supplementary livestock fodder.

Recommended actions: promote as a climate-resilient legume; investigate best-suited areas to be targeted for increased cowpea production; promote as a diverse feedstock for livestock and human consumption.

CLIMATE CHANGE AND ITS EFFECT ON GROUNDNUT

BROAD CONTEXT

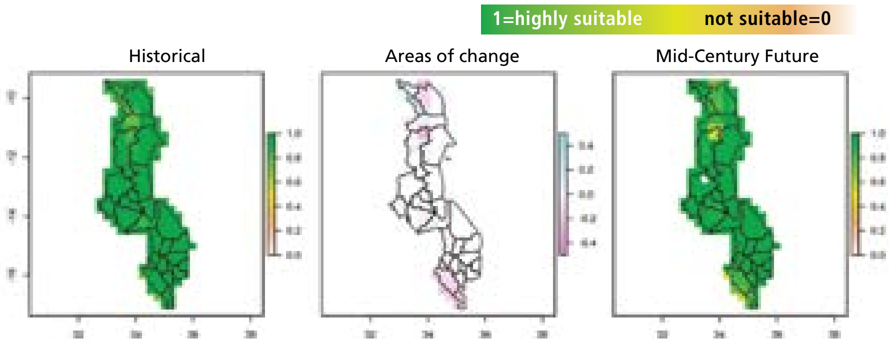
Groundnuts are widely grown as a staple subsistence crop across all of Malawi's ADD regions, where the entire extent of the country is found to be highly suitable.

PRODUCTION OF GROUNDNUTS IN MALAWI[17].

REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	37,847	8.8	33,065	9.3
Karonga	14,376	3.3	14,788	4.1
Kasungu	127,673	29.6	115,433	32.3
Lilongwe	123,139	28.5	106,131	29.7
Machinga	47,526	11.0	22,519	6.3
Mzuzu	58,000	13.4	44,621	12.5
Salima	19,275	4.5	19,292	5.4
Shire Valley	3,848	0.9	1,433	0.4
Total	**431,684**		**357,282**	

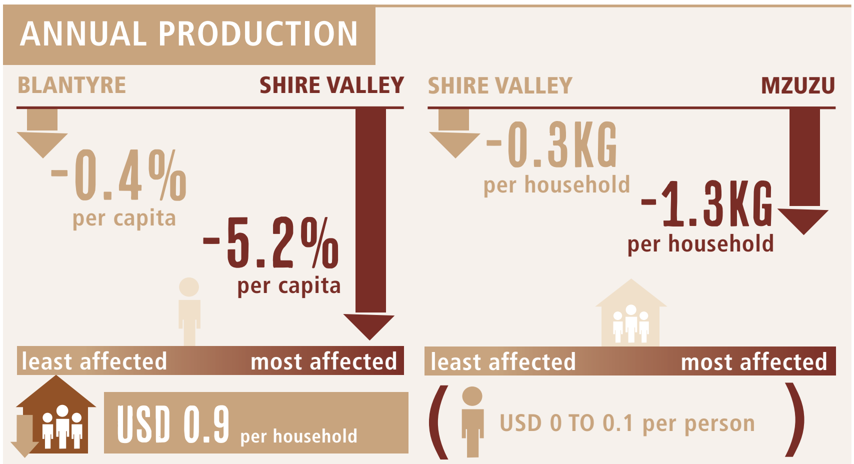
Most ADD regions are expected to undergo only very minor changes to suitability for cultivation of groundnuts as a result of climate change, including both positive and negative effects. All ADD regions are projected to remain highly suitable for groundnuts. Small negative changes to the average suitability index score and resultant productivity are expected in Blantyre, Mzuzu and Shire Valley, ranging from ~-0.4 to -5.2% decreased productivity. However, despite these small decreases in productivity, the latter regions are projected to remain highly suitable. Small positive changes to productivity are also projected for the ADD regions of Lilongwe and Salima. Karonga, Kasungu and Machinga are expected to remain unchanged.

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR GROUNDNUTS IN MALAWI



HOUSEHOLD LEVEL IMPACTS

Blantyre, Mzuzu and Shire Valley are predicted to experience minor negative impacts on groundnut production, where households are projected to experience a decrease of 0.4% (Blantyre) up to 5.2% (Shire Valley) in annual production. However, these changes in annual production are relatively minor at the household level, equivalent to a deficit of 0.3 kg (Shire Valley), 0.4 kg (Blantyre) and 1.3 kg (Mzuzu) per household. The costs of reduced production of groundnuts in these ADDs are estimated to range from USD 0 to 0.1 per person, or, up to USD 0.9 per household[18].



Of the remaining ADD regions, Karonga, Kasunga and Machinga are predicted to remain unchanged, while Lilongwe and Salima may experience very minor positive effects. **These results should not be interpreted as a strong prediction that annual production of groundnuts will increase as a result of climate change,** but rather that those ADDs which benefit from increased suitable area are unlikely to be impacted severely by climate change.

[17] Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

[18] US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for groundnuts varies between districts – average price across all districts was approximately USD 0.6 per kg.

DISTRICT AND NATIONAL-LEVEL IMPACTS

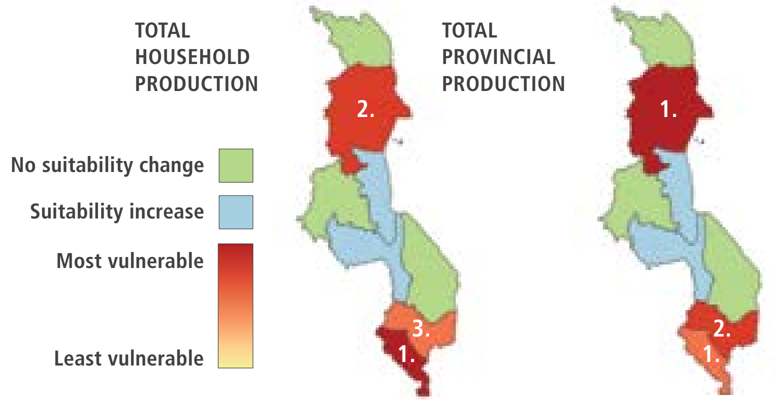
In terms of total annual production of groundnuts within each ADD, it is predicted that Blantyre, Mzuzu and Shire Valley will experience a decrease in annual production ranging from 74 up to 268 tonnes. In total, it is estimated that the annual production of groundnuts across the three negatively affected ADD regions will be reduced by 472 tonnes. These results cannot predict whether the worst-affected ADD regions will be able to benefit from the increased production potential in other ADDs, and consequently these potential positive impacts are not included in the final estimation of changes to annual production. At the ADD scale, it is anticipated that the greatest costs for purchase of replacement food will include Mzuzu (USD 187,000), Shire Valley (USD 80,000) and Blantyre (USD 64,000) regions. At a national scale, the total annual cost of climate-related impacts on groundnuts is estimated to be USD 311,000 per year.

Total annual cost USD 311 000

CLIMATE VULNERABLE ADDS AND HOUSEHOLDS

At the household level, the ADDs which will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Mzuzu (2) and Blantyre (3).
At the ADD level, the most severe negative impacts on total production per administrative region are Mzuzu (1), Blantyre (2) and Shire Valley (3).

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

Malawi will experience a mix of negative, positive and neutral impacts on groundnut production across the ADDs.

The loss of household production of groundnuts is likely to be relatively minor in comparison to other staple crops, but will result in increased costs for households to replace lost production of food.

Cumulative loss of production of groundnuts across all Blantyre, Mzuzu and Shire Valley ADDs is estimated to be 472 tonnes per annum, equivalent to total replacement costs of USD 311,000 per year.

Despite the predicted negative impacts, the continued extensive distribution of suitable areas for groundnut production (particularly in the Central and Northern provinces) suggests that this crop is likely to be a useful option for climate-resilient farming systems.

Recommended actions: promote within diversified, multi-crop and intercrop combinations; research, develop and promote locally-adapted and drought resilient varieties; invest in post-harvest processing facilities and supporting value chains.

CLIMATE CHANGE AND ITS EFFECT ON MAIZE

BROAD CONTEXT

Maize is widely grown as a staple subsistence crop across all of Malawi's ADDs despite widespread areas of only marginal or moderate suitability for long-maturing varieties. In general, short-maturing varieties have widespread areas of excellent suitability (particularly in the northern region adjacent to Lake Malawi, as well as some isolated areas in the east of the southern region). By comparison, EcoCrop analyses of long-maturing varieties indicate that the distribution of suitable areas is relatively limited and characterised by moderate or low productivity.

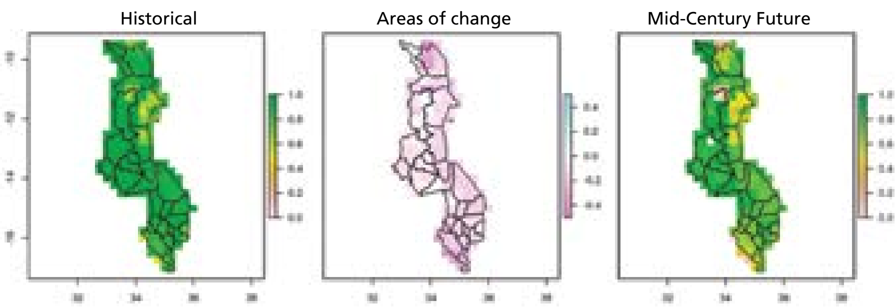
However, despite the apparent suitability of Malawi's climate for short-maturing maize varieties, results suggest that most ADD regions are expected to experience minor or moderate negative changes to suitability for cultivation of short-maturing maize varieties. All regions are predicted to undergo decreases to average suitability index score and resultant negative changes to productivity, ranging from -2.8% to 17.7%. Shire Valley, Salima and Mzuzu are expected to experience the greatest decreased productivity. However, despite these negative changes, the total suitable area for production of short-maturing maize varieties is expected to remain unchanged across all ADDs. Most ADD regions are expected to be characterised by good or very good suitability on average, except for Shire Valley which is expected to be characterised by moderate or good suitability.

In comparison to long-maturing maize varieties, the projected climate change impacts on short-maturing maize varieties are considerably less severe. Although it is expected that short-maturing varieties will undergo some negative changes, overall the total suitable area and average suitability index score indicate that short-maturing maize varieties will remain relatively suitable and productive across all of Malawi's ADD regions.

PRODUCTION OF MAIZE IN MALAWI[19].

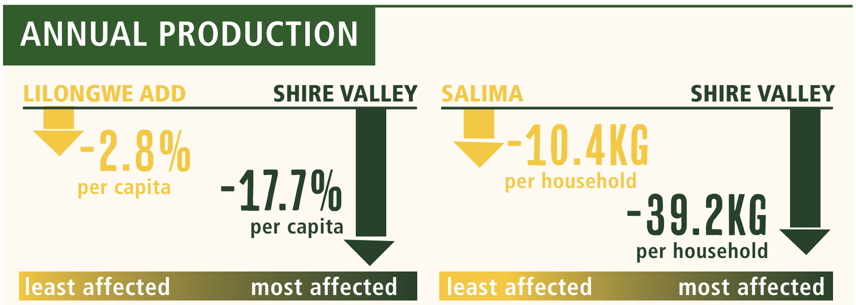
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	224,352	10.1	418,528	17.6
Karonga	60,126	2.7	165,292	6.9
Kasungu	792,455	35.5	666,497	28.0
Lilongwe	654,634	29.4	527,244	22.1
Machinga	218,820	9.8	222,919	9.4
Mzuzu	119,221	5.3	219,284	9.2
Salima	102,417	4.6	102,417	4.3
Shire Valley	57,886	2.6	58,219	2.4
Total	**2,229,911**		**2,380,400**	

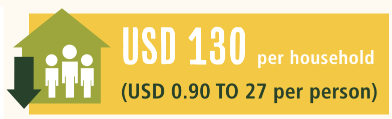
PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR MAIZE IN MALAWI



HOUSEHOLD LEVEL IMPACTS

In the case of short-maturing maize varieties, the total % change of annual production of maize per capita is predicted to range from a loss of 2.8% in Lilongwe ADD up to 17.7% in Shire Valley. At the household level, the projected decrease in production ranges from 10.4kg and 39.2 kg (in Salima and Shire Valley, respectively) up to 76 kg, 81 kg and 164 kg (in the worst affected ADDs of Mzuzu, Blantyre and Kasungu, respectively). The costs of reduced production of maize, assuming short-maturing varieties are adopted throughout Malawi, are estimated to range from USD 0 to USD 5 per person, or, up to USD 26 per household[20].





[19] Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

[20] US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for maize varies between districts – average price across all districts was approximately USD 0.2 per kg.

DISTRICT AND NATIONAL-LEVEL IMPACTS

At the ADD level, the cumulative deficit in production of maize (assuming short-maturing varieties are grown) ranges from 7,050 tonnes in Machinga up to 36,000 tonnes in Kasungu. It is anticipated that the greatest costs for purchase of replacement food will be experienced in Kasungu (USD 5.6 million), Blantyre (USD 4.5 million) and Mzuzu (USD2.6 million) regions. At the national level, it is estimated that the loss of production (assuming short-maturing varieties are adopted across all regions is equivalent to 129,000 tonnes per annum, and resultant replacement costs for lost production are estimated to be USD 21.2 million per year (compared to 640,000 tonnes, or replacement costs of USD 111 million per year, for long-maturing varieties).

Total loss of annual production
129 000 tonnes

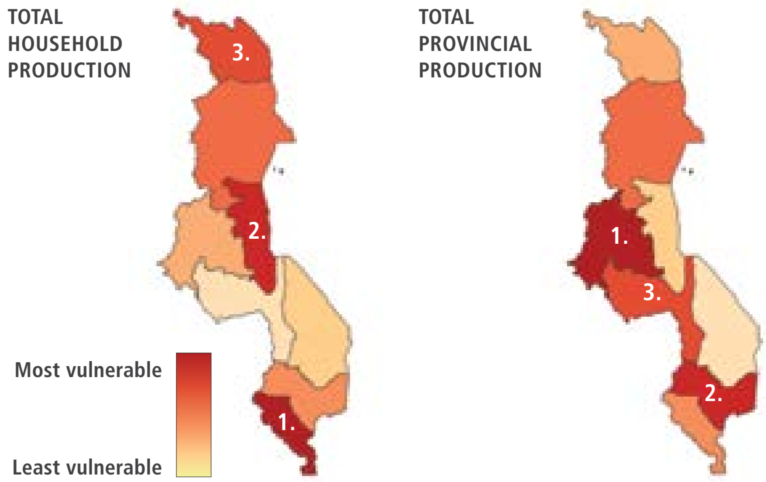
Total annual cost
USD 21.2 million

CLIMATE VULNERABLE ADDs AND HOUSEHOLDS

At the household level, the ADDs that will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Salima (2) and Karonga (3).

At the ADD level, the most severe negative impacts on total production per ADD region are Kasungu (1), Blantyre (2) and Lilongwe (3).

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

Malawi will experience a moderate decrease in the production potential for short-maturing maize varieties as a result of climate change.

Despite the predicted negative changes, wide expanses of the country are likely to be characterised by moderate/good suitability for short-maturing maize varieties.

The total replacement cost for the predicted loss in production of short-maturing varieties is estimated to be USD 21.2 million per year.

The production and economic impacts are predicted to be more severe for long-maturing maize varieties.

Recommended actions: identify and increase access to locally-adapted cultivars; support farmers to adopt climate-resilient practices; promote the adoption of alternative, climate-resilient crops such as sorghum, beans, cowpeas, groundnuts and pigeon peas.

CLIMATE CHANGE AND ITS EFFECT ON PIGEON PEAS

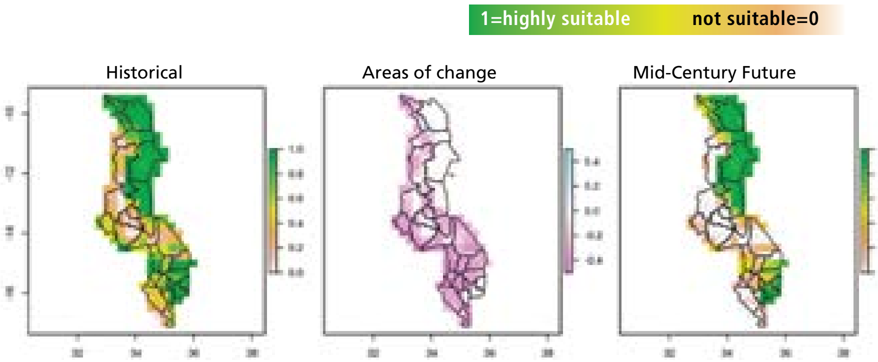
BROAD CONTEXT

Pigeon peas are grown as a subsistence crop across most of Malawi's ADDs, where a large proportion of the country is found to be suitable to some degree. Climate change analyses indicate that most ADD regions are expected to experience moderately or severely negative changes to suitability for cultivation of pigeon peas. The total suitable area is expected to undergo moderate or large decreases (ranging from -4.1% to -53.2%) in all ADD regions, except for Karonga which is likely to remain unchanged in terms of total suitable area. The average suitability index scores and resultant changes to productivity are similarly expected to decrease moderately or severely (ranging from -5% to -59.3%), except for Mzuzu, which will experience minor increases (4.4%) in productivity while simultaneously undergoing a decrease in suitable production area.

PRODUCTION OF PIGEON PEAS IN MALAWI[21].

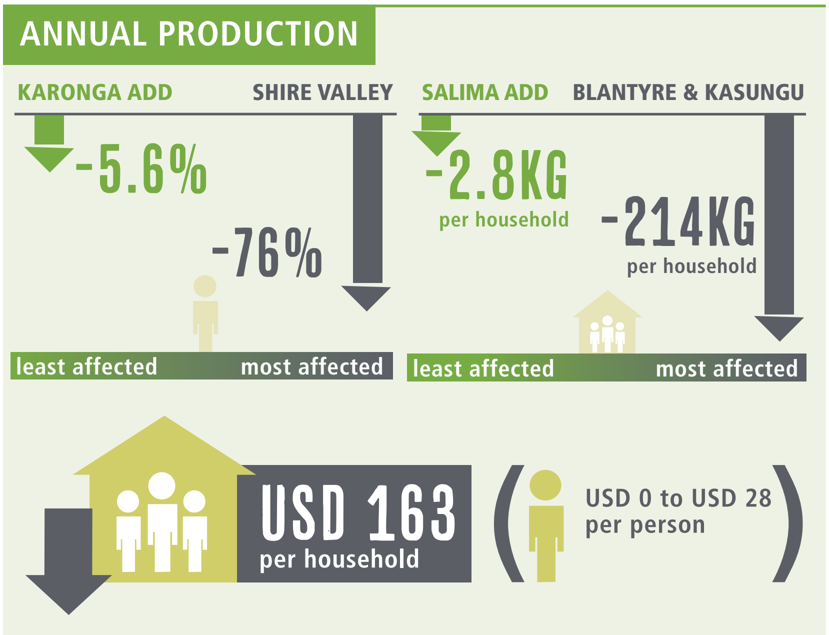
REGION	PRODUCTION AREA		ANNUAL PRODUCTION	
	TOTAL (HA)	% NATIONAL TOTAL	TOTAL (TONNES)	% NATIONAL TOTAL
Blantyre	114,557	26.6	191,287	47.4
Karonga	12,783	3.0	11,185	2.8
Kasungu	83,885	19.5	62,977	15.6
Lilongwe	90,092	20.9	53,751	13.3
Machinga	54,681	12.7	36,198	9.0
Mzuzu	49,942	11.6	29,318	7.3
Salima	3,272	0.8	2,454	0.6
Shire Valley	21,236	4.9	16,434	4.1
Total	**430,448**		**403,604**	

PROJECTED EFFECT OF CLIMATE CHANGE ON DISTRIBUTION OF SUITABILITY FOR PIGEON PEAS IN MALAWI



HOUSEHOLD LEVEL IMPACTS

All ADD regions are predicted to experience moderate to severe negative impacts on production of pigeon peas as a result of climate change. In terms of %changes to production per capita, the effect of climate change will be to reduce production from 5.6% in Karonga ADD up to 76% in Shire Valley. At the household level, losses to annual production of pigeon peas are predicted to range from 2.8 – 3 kg per household in the least affected ADDs (in Salima and Karonga ADDs, respectively), up to 158 kg (Lilongwe), 214 kg (Blantyre and Kasungu) per household. The costs of reduced production of pigeon peas are estimated to range from USD 0 to USD 28 per person, or, up to USD 163 per household.



21 Statistics are derived from the most recent Annual Crop Bulletin (2018) collated by the Department of Crops and Planning, and the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office.

22 US Dollar:Kwacha exchange rate was estimated as 0.0014. Market prices were derived from ADD-level statistics reported in the annual crop bulletin compiled by the Ministry of Agriculture, Irrigation and Water Development, and are further summarised in a supporting Appendix. Market prices for pigeon peas varies between districts – average price across all districts was approximately USD 0.6 per kg.

DISTRICT AND NATIONAL-LEVEL IMPACTS

At the ADD level, the predicted decreases in total annual production are lowest in Salima ADD (annual loss of 595 tonnes). The worst affected ADDs of Blantyre and Kasungu are predicted to experience a decrease of 45,000 tonnes per annum each. In total, the predicted decrease of production of pigeon peas across all ADDs is approximately 160,000 tonnes per annum. At the ADD scale, it is anticipated that the greatest costs for purchase of replacement food will include Lilongwe (USD 34.5 million), Kasungu (USD 20.5 million) and Blantyre (USD 16.2 million) regions. At a national scale, the total annual cost of climate-related impacts on pigeon peas is estimated to be USD 86.5 million per year.

Total loss of annual production **160 000** tonnes

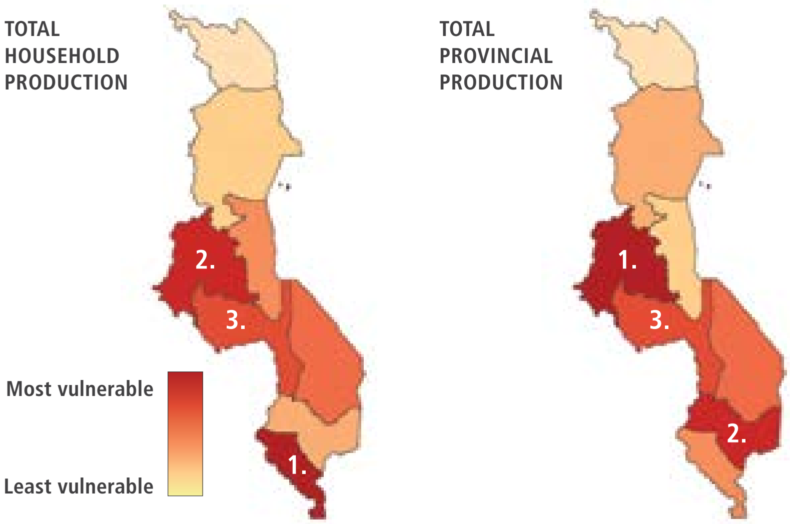
Total annual cost **USD 86.5** million

CLIMATE VULNERABLE ADDS AND HOUSEHOLDS

At the household level, the ADDs that will experience the most severe negative impacts on %change to production per capita (i.e. decreased production relative to average historical production) are Shire Valley (1), Kasungu (2) and Lilongwe (3).

At the ADD level, the most severe negative impacts on total production per ADD region are Kasungu (1), Blantyre (2) and Lilongwe (3).

MOST VULNERABLE REGIONS, BASED ON CHANGES TO:



KEY FINDINGS AND RECOMMENDATIONS

Malawi will likely experience minor to moderate decreases in production of pigeon peas as a result of climate change-related declines in total production area and productivity.

The loss of household production of pigeon peas is likely to be relatively minor in comparison to other staple crops, but will result in increased costs for households to replace lost production of food – particularly in Shire Valley, Kasungu, Lilongwe and Blantyre.

Cumulative loss of production of pigeon peas across all ADDs is estimated to be 160,000 tonnes per annum, equivalent to total replacement costs of USD 86.5 million per year.

Despite the predicted negative impacts, the continued extensive distribution of suitable areas for pigeon peas suggests that this drought-tolerant and versatile crop is likely to be a useful option for climate-resilient farming systems.

Recommended actions: promote within diversified, multi-crop and intercrop combinations; research, develop and promote locally-adapted and drought resilient varieties; invest in post-harvest processing facilities and supporting value chains.

SUMMARY OF FINDINGS, RECOMMENDATIONS, ADAPTATION STRATEGIES AND CLIMATE-RESILIENT ALTERNATIVES FOR SMALLHOLDER FARMERS

The summarised findings above indicate that several important staple crops – notably beans, cassava and maize – are predicted to experience significant decreases in production. Consequently, it is strongly recommended that initiatives related to climate change adaptation, food security and enhanced agricultural production include careful consideration of strategies to increase the resilience of the latter three crops. This may include specific strategies to safeguard the production of traditional staples and other crops, as well as broader measures to diversify agricultural income and food production in general (for example, development of irrigation and water resources, strengthening of livestock production systems, strengthening of value chains and agro-processing facilities).

In the case of maize, results strongly support the case for development and promotion of fast-growing, early-maturing varieties to be disseminated as widely as possible. Despite the prediction of negative impacts on the early-maturing varieties, these are predicted to be considerably less severe and costly than the negative impacts incurred by households growing late-maturing maize varieties. In addition, the risk of reduced production of all maize varieties can be partly offset by continued promotion of crop diversification, including intercropping and multi-crop approaches that include diverse legumes and alternative cereals such as sorghum and millet (both as a result of increased promotion by government and development agencies as well as voluntary shifts to climate-resilient alternatives to maize). This study could not find adequate baseline data for sorghum production at the ADD level and therefore could not assess the relative vulnerabilities of sorghum to climate change – however, results indicate that sorghum production can be expected to undergo relatively minor negative effects and the majority of Malawi is characterised by moderate or good suitability for sorghum production in the future

In the case of beans, the results indicate a moderate or severe reduction of production as a result of climate change. Despite this predicted negative trend, beans and other leguminous crops are still expected to be a useful component of future strategies to adapt smallholder agriculture to climate change in Malawi. The crop is already widely grown and eaten, can be incorporated into diverse inter-cropping and crop rotation strategies with other staple crops, and contributes positively to soil fertility. The potential risk of negative impacts of climate change on beans can partly be offset by promoting the adoption of a diversity of bean cultivars as well as additional legume species, notably including cowpea and groundnuts which are predicted to remain relatively resilient to the changing climate.

In the case of cassava, climate change is predicted to result in negative effects on production in the Southern region but with possible positive effects in some of the Central and North districts. It is recommended that future initiatives focused on increasing the climate change resilience of Malawi's cassava farmers and food security should include a focus on development of facilities and a supporting value chain for post-harvest processing and value addition of cassava. The ability to process fresh cassava roots into chips, flour, starch or other shelf-stable products will reduce the loss of fresh cassava to waste and spoilage, thereby contributing to food security and providing farmers with a potential source of income. Furthermore, the production of cassava in Malawi can be further strengthened by initiatives that promote access to good-quality plant materials, focusing on virus-free clones of high-yielding and locally-adapted varieties. In addition, it is recommended that farmers are provided with capacity building and training to control pests and diseases, particularly to control the insect vectors of cassava mosaic virus as well as to identify and remove infected plants.

APPENDIX TABLES

APPENDIX TABLE A.1.

SUMMARISED ADAPTIVE CAPACITY (AC) INDICATORS COLLECTED FOR ALL PROVINCES OF MALAWI[23]

Indicator category	Adaptive capacity indicators	Blantyre	Karonga	Kasungu	Lilongwe	Machinga	Mzuzu	Salima	Shire Valley
Adoption of improved agricultural practices	% Fertilizer use among smallholder farmers	77.5	51.2	56.2	66.7	68.6	71.2	55.0	19.3
	% Use of manure	0.7	0.5	0.2	0.0	0.8	0.5	0.0	1.1
	% Use of herbicide	9.6	7.7	21.0	20.4	9.4	21.5	3.5	5.1
Access to agricultural information	% Agricultural households with a cellular phone	47.8	52.2	47.1	47.6	42.5	72.2	45.3	34.5
Access to alternative income	% Households operating a non-agricultural enterprise	28.7	30.4	23.1	30.4	20.3	31.5	19.5	29.3
	$ Households reporting adequate food	38.3	26.2	26.0	35.3	23.2	36.0	31.3	24.3
Education	% Literacy rate (15+)	11.5	7.3	14.3	12.6	9.3	20.6	16.1	13.1
Education	% Households that obtained a loan	75.7	80.8	72.9	72.7	65.8	87.1	65.3	59.3

[23] Derived from the most recent statistics published in the fourth Integrated Housing Survey (2016-17) published by the National Statistical Office, http://www.nsomalawi.mw/images/stories/data_on_line/economics/ihs/IHS4/IHS4%20REPORT.pdf

APPENDIX TABLE A.2.

PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY TEMPERATURE (°C) IN THE ADDS OF MALAWI AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS

		MONTH											
		J	F	M	A	M	J	J	A	S	O	N	D
BLANTYRE	Historical (°C)	22.3	22.2	22.3	21.7	20.3	18.6	18.2	19.5	21.6	23.5	24.2	23.2
	Future (°C)	24.1	24.1	24.1	23.6	22.2	20.7	20.3	21.4	23.6	25.6	26.5	25.3
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.9*	*1.9*	*2.1*	*2.1*	*1.9*	*2.0*	*2.0*	*2.3*	*2.1*
KARONGA	Historical (°C)	23.1	23.0	23.1	22.3	20.7	18.7	18.2	19.6	22.0	24.2	24.9	24.0
	Future (°C)	24.9	24.8	24.9	24.2	22.6	20.8	20.2	21.5	24.0	26.2	27.3	26.2
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.9*	*2.0*	*2.0*	*2.1*	*1.9*	*2.0*	*2.0*	*2.4*	*2.2*
KASUNGU	Historical (°C)	24.3	24.2	24.3	23.5	22.0	20.1	19.7	21.0	23.6	25.7	26.4	25.3
	Future (°C)	26.1	26.0	26.2	25.3	24.0	22.1	21.7	22.9	25.6	27.7	28.9	27.4
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.8*	*2.0*	*2.0*	*2.0*	*1.9*	*2.0*	*2.0*	*2.5*	*2.2*
LILONGWE	Historical (°C)	22.9	23.0	23.0	22.1	20.5	18.6	18.1	19.7	22.7	24.7	25.3	24.0
	Future (°C)	24.7	24.9	24.9	23.9	22.6	20.7	20.2	21.6	24.7	26.8	27.8	26.2
	Anomaly (°C)	*1.8*	*1.8*	*1.9*	*1.8*	*2.0*	*2.1*	*2.1*	*2.0*	*2.0*	*2.0*	*2.6*	*2.2*
MACHINGA	Historical (°C)	23.3	23.2	23.2	22.3	20.6	18.7	18.3	19.8	22.6	24.6	25.2	24.0
	Future (°C)	25.1	25.0	25.1	24.1	22.6	20.7	20.3	21.7	24.6	26.7	27.9	26.2
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.8*	*2.0*	*2.0*	*2.0*	*1.9*	*2.0*	*2.2*	*2.6*	*2.2*
MZUZU	Historical (°C)	25.1	24.8	24.9	24.0	22.3	20.5	20.2	21.6	24.2	26.2	27.0	25.7
	Future (°C)	26.9	26.6	26.8	25.8	24.2	22.4	22.1	23.5	26.1	28.4	29.5	27.9
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.8*	*2.0*	*1.9*	*2.0*	*1.9*	*1.9*	*2.1*	*2.5*	*2.1*
SALIMA	Historical (°C)	26.0	25.7	25.5	24.4	22.4	20.6	20.3	21.8	24.4	26.6	27.4	26.4
	Future (°C)	27.8	27.4	27.4	26.3	24.4	22.5	22.3	23.7	26.3	28.7	30.0	28.6
	Anomaly (°C)	*1.9*	*1.8*	*1.8*	*1.9*	*2.0*	*1.9*	*2.0*	*1.8*	*1.9*	*2.2*	*2.6*	*2.1*
SHIRE VALLEY	Historical (°C)	28.0	27.6	27.4	26.3	24.2	22.1	21.9	23.4	26.1	28.4	29.3	28.5
	Future (°C)	29.8	29.4	29.3	28.2	26.2	24.1	23.9	25.2	28.0	30.7	32.0	30.6
	Anomaly (°C)	*1.8*	*1.8*	*1.8*	*1.9*	*2.1*	*1.9*	*2.0*	*1.8*	*1.9*	*2.3*	*2.7*	*2.1*

APPENDIX TABLE A.3.

PROJECTED INFLUENCE OF CLIMATE CHANGE ON MEAN MONTHLY PRECIPITATION (MM/MONTH) IN THE ADDS OF MALAWI AT HISTORICAL AND MID-CENTURY PERIODS, AND MONTHLY ANOMALIES BETWEEN THE TWO TIME PERIODS

mm/month		MONTH												TOTAL
		J	F	M	A	M	J	J	A	S	O	N	D	
BLANTYRE	Historical	215.5	193.6	245.8	171.8	52.7	16.9	12.9	5.2	2.9	9.1	67.8	183.0	**1177.2**
	Future	204.9	184.8	236.0	149.8	33.6	10.7	7.5	3.0	1.4	5.0	41.7	161.1	**1039.5**
	Anomaly	*-10.5*	*-8.8*	*-9.8*	*-22.0*	*-19.1*	*-6.3*	*-5.4*	*-2.1*	*-1.6*	*-4.1*	*-26.2*	*-21.9*	***-137.7***
KARONGA	Historical	234.4	210.4	232.2	134.1	36.5	11.7	12.3	3.9	3.9	12.2	68.9	195.6	**1156.1**
	Future	222.3	198.5	217.5	116.9	25.9	7.4	7.5	2.6	1.8	6.5	43.2	169.0	**1019.1**
	Anomaly	*-12.1*	*-11.9*	*-14.6*	*-17.2*	*-10.6*	*-4.3*	*-4.8*	*-1.3*	*-2.1*	*-5.7*	*-25.7*	*-26.6*	***-137***
KASUNGU	Historical	268.5	231.8	231.1	94.0	13.8	5.5	5.6	3.0	3.1	8.5	55.0	209.2	**1129.1**
	Future	255.3	223.6	212.6	80.8	10.6	3.5	3.4	2.1	1.6	4.1	35.7	186.9	**1020.2**
	Anomaly	*-13.2*	*-8.2*	*-18.5*	*-13.2*	*-3.2*	*-2.0*	*-2.2*	*-0.9*	*-1.5*	*-4.4*	*-19.3*	*-22.3*	***-108.9***
LILONGWE	Historical	235.4	199.0	150.2	45.2	6.3	1.3	1.3	1.2	1.9	9.9	62.5	191.5	**905.7**
	Future	223.8	193.4	138.0	38.1	4.8	0.9	0.8	1.1	1.0	4.7	42.0	170.5	**819.1**
	Anomaly	*-11.6*	*-5.5*	*-12.2*	*-7.1*	*-1.5*	*-0.4*	*-0.5*	*-0.1*	*-0.9*	*-5.2*	*-20.5*	*-21.0*	***-86.6***
MACHINGA	Historical	245.4	206.6	147.6	43.6	8.2	3.9	4.1	5.3	6.6	15.9	65.6	201.0	**953.8**
	Future	230.9	198.7	132.0	35.2	6.2	2.6	2.9	3.9	3.4	7.6	43.2	179.7	**846.3**
	Anomaly	*-14.4*	*-7.9*	*-15.7*	*-8.4*	*-2.0*	*-1.3*	*-1.2*	*-1.5*	*-3.2*	*-8.2*	*-22.4*	*-21.3*	***-107.5***
MZUZU	Historical	248.7	219.0	158.9	46.5	9.6	6.5	7.1	11.2	10.2	20.4	63.6	208.9	**1010.6**
	Future	233.2	208.2	139.4	38.3	7.4	4.9	5.3	7.8	5.9	10.8	40.4	186.4	**888**
	Anomaly	*-15.4*	*-10.8*	*-19.6*	*-8.3*	*-2.2*	*-1.7*	*-1.7*	*-3.4*	*-4.3*	*-9.5*	*-23.1*	*-22.5*	***-122.6***
SALIMA	Historical	236.3	203.9	163.7	65.0	21.5	16.3	18.5	12.2	12.4	38.5	85.5	198.7	**1072.5**
	Future	221.8	191.7	141.0	51.4	16.6	12.4	14.5	9.0	6.6	18.8	56.0	176.2	**916**
	Anomaly	*-14.6*	*-12.2*	*-22.7*	*-13.6*	*-4.9*	*-3.9*	*-4.0*	*-3.2*	*-5.7*	*-19.7*	*-29.5*	*-22.5*	***-156.5***
SHIRE VALLEY	Historical	197.4	165.4	118.3	42.6	16.9	16.4	15.5	9.3	8.6	27.4	70.3	161.9	**850**
	Future	184.9	156.0	102.1	33.3	12.8	12.3	11.9	7.2	4.4	12.1	46.4	144.5	**727.9**
	Anomaly	*-12.5*	*-9.3*	*-16.3*	*-9.3*	*-4.2*	*-4.1*	*-3.6*	*-2.1*	*-4.2*	*-15.4*	*-23.9*	*-17.4*	***-122.1***