MALAWI CLIMATE CHANGE VULNERABILITY ASSESSMENT: ANNEX D. CROP PHENOLOGY

African and Latin American Resilience to Climate Change (ARCC)

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CONTENTS

1.0 INTRODUCTION 1
1.1 METHODOLOGY, ASSUMPTIONS, AND CONSTRAINTS 1
1.2 SUMMARY OF CLIMATE IMPACTS ON SIX KEY CROPS 2
1.2.1 Maize 2
1.2.2 Sorghum 2
1.2.3 Groundnuts 3
1.2.4 Pigeon Peas 3
1.2.5 Cowpeas 3
1.2.6 Soybeans 3
2.0 POTENTIAL IMPACTS ON YIELD AND THE PREVALENCE OF PESTS AND DISEASES 7
2.1 MAIZE 8
2.1.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Maize 12
2.1.2 Maize: Agronomic Calendar for Planting and Harvesting in Malawi 13
2.2 SORGHUM 14
2.2.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Sorghum 18
2.2.2 Sorghum: Agronomic Calendar for Planting and Harvesting in Malawi 19
2.3 GROUNDNUTS 20
2.3.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Groundnut 23
2.3.2 Groundnuts: Agronomic Calendar for Planting and Harvesting in Malawi 24
2.4 PIGEON PEAS 25
2.4.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Pigeon Peas 30
2.4.2 Pigeon Peas: Agronomic Calendar for Planting and Harvesting in Malawi 31
2.5 COWPEAS 32
2.5.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Cowpea 36
2.5.2 Cowpeas: Agronomic Calendar for Planting and Harvesting in Malawi 37
2.6 SOYBEANS 38
2.6.1 Table of Optimal Ranges of Temperatures and Rainfall Required at Phenological Stages of Soybean 41
2.6.2 Soybeans: Agronomic Calendar for Planting and Harvesting in Malawi 42

1.0 INTRODUCTION

This annex examines in detail potential impacts of projected climate variations on phenological stages of six crops currently cultivated in Malawi. With a climate commonly described as tropical, the temperatures in the mountain regions of the country are moderately cool.

Climate projections described in other sections of this report suggest that average annual temperatures in Malawi will increase between 1.2 and 3.5°C by the year 2060. The range of projections for changed in mean rainfall is large–projections from different models includes both negative and positive changes; but seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall. Specifically, climate projections carried out under this Malawi Vulnerability Assessment (VA) project reduced average monthly rainfall during the months of December and January, and increased average monthly rainfall during the months between February and April. As discussed in other portions of this report, inter-annual unpredictability in the levels of rainfall is high, and is related to fluctuations in temperatures of the Indian Ocean, which can be different from one year to another.

This annex provides a detailed analysis of the vulnerability of the responses of the phenological stages of six crops to projected temperature and rainfall variations. As in most parts of Africa, crops utilized in Malawi are adapted to the limited fertility of the soils and unpredictable sources of water. In general, agriculture and crop production in Malawi rarely reach full potential and, rather that they are substandard and poor. The analyses described in this annex indicate that the impact of changes in temperature and rainfall can be more significant in the early stages of the plant development, especially at the stages of germination and early emergence. These are phases in development where water availability plays a substantial role in plant health and plant viability. Any damage at these early phenological stages can be very important because even if the plant recovers, the damage can be carried on to later stages and affect growth, flowering, fruiting, and yield.

That said, an excess of water can also be a serious constraint under a scenario of excessive rainfall. The problem is exacerbated in fields with poor drainage which can create a prolonged exposure of the crops to water logging stress. The most vulnerable areas to floods in Malawi are the river valleys, the lakeshore plain, and the Upper Middle and Lower Shire Valleys. Recent floods have occurred in some of these areas from 2000 to 2004.

As with all second-degree impacts (as defined in the Malawi VA study), the potential impacts of climate change and climate variability can be at least partially addressed by adaptation actions taken by local farmers and breeders, such as modifications in planting dates, breeding efforts, and/or use of different cultivars. Because these human-driven actions are difficult to predict, potential options to counter negative impacts on plant development and productivity in the face of climate change are not captured by this analysis, which is focused only on phonological responses to climate change and climate variability.

1.1 METHODOLOGY, ASSUMPTIONS, AND CONSTRAINTS

The climate analysis conducted as part of the Malawi VA clearly demonstrated how weather in Malawi is strongly influenced by surface temperatures originated in the Indian Ocean, which can vary considerably from one year to another due to deviations in the patterns of atmospheric and oceanic circulation. The country is situated in a location of influences by the Niño Southern Oscillation (ENSO) , an Indo-Pacific phenomenon that may modulate circulation in the Indian and Atlantic oceans; the Indian Ocean Dipole, (IOD), an equatorial pattern that affects rainfall primarily over equatorial Africa, but which may also impact subtropical southern Africa; and the Subtropical Indian Ocean Dipole (SIOD), a pattern further south of the IOD that may be linked to higher than normal rainfall in southern Africa. Recent evidence indicates that weather in Malawi may also be significantly influenced by Atlantic Ocean sea surface temperatures. This situation cause

mixed climate responses in Malawi, contributing to considerable uncertainty in climate projections for the region. In addition to the climate analysis conducted under the Malawi VA, two other climate models were used to predict the potential impacts of changes in climate conditions on different phenological stages of select crops grown in the study zone. These were the climate model created by the United Nations Development Programme (UNDP) for Malawi (McSweeney et al. 2010) and the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM3) climate model (Christensen et al. 2007; Govindasamy et al. 2003; Kiehl et al. 1996; Meehl et al 2007). The findings from these studies were combined to determine the climate parameters that would be considered for this phonological study: A mean increase of averaged annual temperature between 1.2 and 2.5°C and between 1.1 to 3.0℃ by the year 2060, and projections of rainfall that include both negative and positive changes (-13 percent to +32 percent).

The phenological study was carried out through a review the scientific and technical literature to identify how climate conditions impact different phenological stages of select crops grown in the study zone, and also how climate can influence the occurrence and outbreak of common pests and diseases observed in Malawi. The conclusions on the impacts are relative to vulnerability to climate change within optimal plant growth ranges, and indicators of impact are extrapolated from existing literature and do not necessarily obtain a high level of confidence.

The available scientific and technical literature sources relevant to Malawi were limited and the information in them was sometimes contradictory. For the more commonly studied crops, such as maize, cassava, and sorghum, there were more sources of information than for minor crops. Even for the major crops, the sources of information specific to Malawi were limited. Thus, the study complemented with findings from other areas of Africa or even other areas of the world with similar climate conditions.

Contradictory information–such as one report finding a negative correlation between a pest and temperature, and another finding a positive correlation between them–was resolved by reviewing additional information that would corroborate the sources.

1.2 SUMMARY OF CLIMATE IMPACTS ON SIX KEY CROPS

The six crops studied were those of the Malawi VA: Maize, sorghum, pigeon peas, groundnuts, cowpeas, and soybeans. This section provides a brief overview of these six crops. The next section presents a detailed analysis of the climate change impacts on the six crops.

1.2.1 MAIZE

Maize is considered to be the most important food staple in Malawi. Consumption reaches up to 133 kg per capita and accounts for about 54 percent of the caloric intake of rural households. It is the most broadly grown cereal, covering 76 percent of farmlands. However, drought episodes occurring regularly since 1990 have critically hurt maize production. The dependence on rain-fed maize has also resulted in food shortages taking place every two or three years. Traditional varieties in Malawi can produce well under high temperature conditions. However, production and yield are highly susceptible to water stress and poor levels of micro-nutrients in soil.

1.2.2 SORGHUM

Sorghum was a very important staple before the introduction of maize in Malawi and is still regularly grown by local farmers. Sorghum is mainly grown in the Central and Northern regions of the country: Salima, Machinga, and Karonga for lowlands and Shire Valley district for highland regions. The primary uses of sorghum are for food ("*nsima*") and for brewing beer. Sorghum production is limited by a number of factors such as the lack of better cultivars, inadequate crop production practices, drought, pests, and diseases. Recently, production has been increasingly affected by poor and unpredictable rainfall.

1.2.3 GROUNDNUTS

Malawi is one of the most important groundnut-producing countries in southern Africa. Groundnuts account for 25 percent of household-level agricultural income in the country. Moreover, groundnuts help fix atmospheric nitrogen in soils, enhancing soil fertility. Groundnuts are cultivated as a rain-fed crop either alone or in association with cereals such as maize and sorghum, millet, or grain legumes such as pigeon peas. Apart from the infrequent utilization of improved varieties, low productivity can be attributed to biotic and abiotic stresses and low soil fertility. Average yields in Malawi are poor (700kg/ha) compared to yield over 2500 kg/ha obtained in the developed world. Groundnut hulls are also valuable as fodder for animals and fuel. Groundnuts grow in a range of altitude of 200–1,500 meters with the majority grown in the Central region (Lilongwe and Kasungu districts) at around 1,200 meters.

1.2.4 PIGEON PEAS

Pigeon peas rank as the third-most important legume crop after groundnuts and beans; an estimated 65 percent of the pigeon peas produced in Malawi are consumed by the farm households. Poor production practices make this crop susceptible to insect and other pest damage. Lack of crop rotation is the leading cause of a high incidence of wilt caused by *Fusarium*. Another negative factor is the presence of aflatoxin which makes the product unhealthy for human and animal consumption. Pigeon pea cultivation is heavily concentrated in the Blantyre, Machinga, and Shire Valley districts. This crop can withstand low moisture condition and performs well in areas with low levels of rainfall. Pigeon peas can be planted with crops such as maize, sorghum, or groundnuts without significantly reducing the yield of the main crop. Intercropping with maize and groundnuts is very common in Malawi.

1.2.5 COWPEAS

Cowpeas (*Vigna unguiculata)* are important for poor rural regions throughout the semi-arid and sub-humid areas of East and Southern Africa. Cowpeas are widely known as "the crop of the poor" because the plant's green pods and leaves are the earliest food available before cereals mature so serving as "insurance" against food shortages during the "hungry season." The areas in which cowpeas are cultivated are often inappropriate for the production of other crops such as beans or peanuts, but cowpea yields in these farmer-managed fields are low, averaging only 388 kg/ha in Malawi. Different abiotic and biotic stresses keep productivity low. The most significant of these are drought; heat; poor soil fertility; inappropriate agronomic practices; fungal, viral, and bacterial diseases; and parasitic weeds (*Striga* and *Alectra*). Cowpeas are particularly susceptible to infestation by several insects with devastating effects on plants in the field and seeds in storage.

1.2.6 SOYBEANS

Soybeans can grow from sea level up to 2,000 meters and under a broad range of temperature; however the most favorable temperature for growth and development is around 30°C, whereas for appropriate seed emergence the optimal temperature is between 25–33°C. Soybeans require low water input; rainfall levels of 500–850 mm during the growing season are good. Depending on the variety and growing conditions, soybeans can mature between 65 and 150 days after planting. This crop that offers an important source of proteins and oil (an average protein content of 40 percent and oil content of 20 percent). Like most food crops grown in Africa, the production of soybeans is mainly rain-fed and often grown by small-scale farmers on small land areas and in various mixed cropping systems. The lack of varieties with tolerance to water stress and high yielding varieties tolerant to low phosphorus in soil are among the most significant abiotic constraints.

Table1on the following page provides a summary of climate change impacts on the six key crops. Section 2.0 provides detailed information on potential climate change impacts on crop yield and the prevalence of pests and diseases. The potential climate change impact on each crop is described in two parts: The first describes the potential influence of posited changes in rainfall and temperature on the success of each vegetative and

reproductive stage; the second shows the how the same changes in climate may influence the ability of diverse pests and diseases to infest or infect select crops at their different phenological stages.

It is noted that the conclusions are subject to the limitations described in Section 1.1 "Methodology, Assumptions, and Constraints."

TABLE 1. SUMMARY OF CLIMATE CHANGE IMPACTS ON SIX CROPS

Maize	
Impact on maize productivity	High to very high potential for decrease in productivity, both reproductive and vegetative stages can be impacted by extreme temperature and rainfall variations. Combination of extreme heat and long droughts can significantly impact plant development.
Termites *Microtermes sp. and others*	Moderate to high potential for increase in prevalence, particularly under warmer than normal temperatures and decreased rainfall scenarios.
Gray Leaf Spot *Cercospora zeae-maydis*	High potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios.
Turcicum Leaf Blight *Exserohilum turcicum*	Moderate to high potential for increased prevalence, particularly under increased rainfall and cooler than normal temperature scenarios.
Maize Streak Virus	Moderate to high potential for increase in prevalence, particularly under decreased rainfall scenarios and warmer than normal temperatures which promotes higher vector incidence. Outbreaks of maize streak have been associated with drought and irregular rain.
Sorghum	
Impact on sorghum productivity	Moderate potential for decrease in productivity, particularly during seed germination and initiation as well as 3-and 5-leaf stages and root growth. It shows good adaptability in later reproductive stages.
Covered smut (*Sphacelotheca sorghi*) and loose smut (*S. cruenta*)	Moderate potential for increased prevalence, particularly sensitive to water availability and will possibly decrease in prevalence under warmer than normal conditions
Spotted Stemborer *Chilo partellus*	Moderate to high potential for increased prevalence, particularly under decreased rainfall and warmer than normal temperature scenarios.
Rust *Puccinia purpurea*	Moderate to high potential for increased prevalence, particularly in vegetative stages and under increased rainfall and warmer than normal temperature scenarios.
Sorghum Aphid *Melanaphis saccari*	Moderate potential for increased prevalence, particularly sensitive to water availability and will possibly decrease in prevalence under warmer than normal conditions.
Anthracnose *Colletotrichum graminicola*	High potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios.
Groundnuts	
Impact on groundnut productivity	High potential for decrease in productivity under variable precipitation and temperature scenarios. Different developmental stages at both vegetative and reproductive phases can be affected.
Yellow Witchweed *Alectra vogeli*	Moderate to high potential for increase in prevalence, particularly under warmer than normal temperatures and decreased rainfall scenarios. Yield losses may range from 41% to total crop lost.
Groundnut rosette virus (GRV)	Moderate to high potential for increase in prevalence, particularly under decreased rainfall scenarios and warmer than normal temperatures which promotes higher vector incidence. It can cause losses of up to 90%.
Web Blotch *Phoma arachidicola*	Moderate to high potential for increased prevalence, particularly under increased rainfall and cooler than normal temperature scenarios.

Pigeon peas	
Impact on pigeon pea productivity	Slight to moderate potential for decrease in productivity. Seed yield that includes grain filling, maturity and ripening are reported to be sensitive to drought.
Root-Knot Nematode *Meloidogyne javanica*	Moderate to high potential for increased prevalence, particularly under decreased rainfall and warmer than normal temperature scenarios. Nematodes are found in warmer and drier soils.
Fusarium Wilt *Fusarium udum*	Moderate potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios. This is the most prevalent and destructive disease of pigeon pea, affects reproductive and vegetative stages.
Leaf spots, stem canker *Xanthomonas campestris pv cajani*	High potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios.
Cowpeas	
Impact on cowpea productivity	Slight to moderate potential for decrease in productivity, critical stages are emergence, seedling growth and root development. Cowpea displays good adaptability in reproductive stages.
Pod Borer, Cowpea Caterpillar *Maruca vitrata*	Moderate to high potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios. Adults are most active during the rainy season.
Root-Knot Nematode *Meloidogyne javanica*	Moderate to high potential for increased prevalence, particularly under decreased rainfall and warmer than normal temperature scenarios. Nematodes are found in warmer and drier soils.
Soybeans	
Impact on soybean productivity	Slight to very slight potential for decrease in productivity. Most stages in both reproductive and vegetative phases appear to have enough adaptability for changes in temperature and rainfall. Inflorescence and floral development can be critical stages.
Soybean Rust *Phakopsora pachyrhizi*	High potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios. It is the most destructive foliar disease of soybean; affects all stages of crop development.
Root-Knot Nematode *Meloidogyne mayaguensis*	High potential for increased prevalence, particularly under increased rainfall and warmer than normal temperature scenarios.

2.0 POTENTIAL IMPACTS ON YIELD AND THE PREVALENCE OF PESTS AND DISEASES

Please use the following legend for each of the Phenological Stages tables in this section.

LEGEND

+	Favorable conditions expected to increase productivity of crops; increase pest/disease attacks on crops
0	Little or no influence or impact expected
-	Non-favorable conditions expected to decrease productivity of crops; decrease pest/disease attacks on crops

2.1 MAIZE

MAIZE																								
	Vegetative Stages								Reproductive Stages															
Phenological Stages	Germination and emergence				Leaf development, stem elongation				Inflorescence development				Flowering, anthesis				Development of fruit, grain development, milking				Ripening, Senescence and Harvesting			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on maize productivity [1]	+	-	-	-	+	-	-	+	+	-	-	0	-	-	-	0	+	-	-	-	+	-	-	0

[1] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

MAIZE PESTS AND DISEASES																								
	Germination and emergence				Leaf development, stem elongation				Inflorescence development				Flowering, anthesis				Development of fruit, grain development, milking				Ripening, Senescence and Harvesting			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
MAIZE PESTS																								
Larger Grain Borer *Prostephanus truncatus*[2]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	+	+	0
Spotted stemborer *Chilo partellus*	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
Maize weevil *Sitophilus zeamais*[3]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-
Angoumois Grain Moth *Sitotroga cerealella*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0

[2] Both adults and larvae feed internally on maize grains and an infestation can start in the field.

[3] Breeding conditions require temperatures between 15 and 34° C and 40% relative humidity.

Stem Borer *Busseola fusca*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-
Pink Stem Borer *Sesamia calamistis*[4]	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-
Termites *Microtermes sp., Macrotermes sp., Allodontermes spp.,Odontotermes spp)*[5]	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
Striga Weed *Striga asiatica*	+	0	+	0	+	-	+	0	+	0	+	0	0	+	+	0	0	+	+	0	+	0	0	+
VIRAL DISEASSES																								
Maize Streak Virus[6]	+	-	+	0	+	-	+	0	+	-	+	-	+	-	0	0	+	-	0	0	+	0	+	0
FUNGAL DISEASES																								
Sorghum downy mildew *Peronosclerospora sorghi*	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Turcicum Leaf Blight *Exserohilum turcicum*	+	-	0	+	+	-	0	+	+	-	0	+	+	-	0	+	+	-	0	+	+	-	0	+
Gray Leaf Spot *Cercospora zeae-maydis*	0	0	0	0	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0

[4] This species is found in sub-Saharan Africa.

[5] Twenty-seven species of termites are known for attacking crops in Malawi. The most frequently crop attacked is maize.

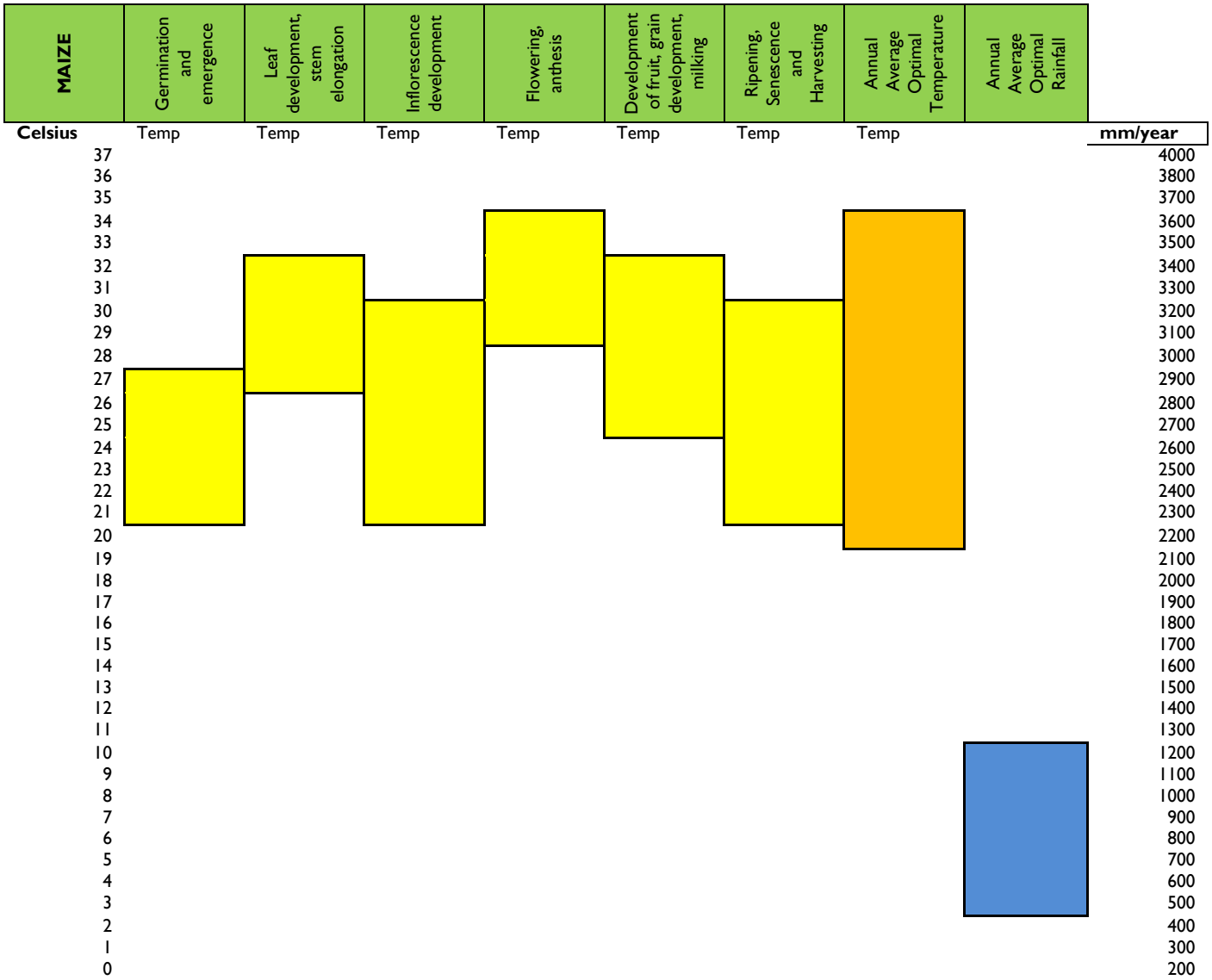
[6] Outbreaks of maize streak have been associated with drought and irregular rain.

Southern Corn Leaf Blight *Bipolaris maydis*[7]	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0
Rust *Puccinia sorghi*[8]	0	0	0	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	0	0	0	0

[7] Seedlings from seeds infected often wilt and die within 3 to 4 weeks.

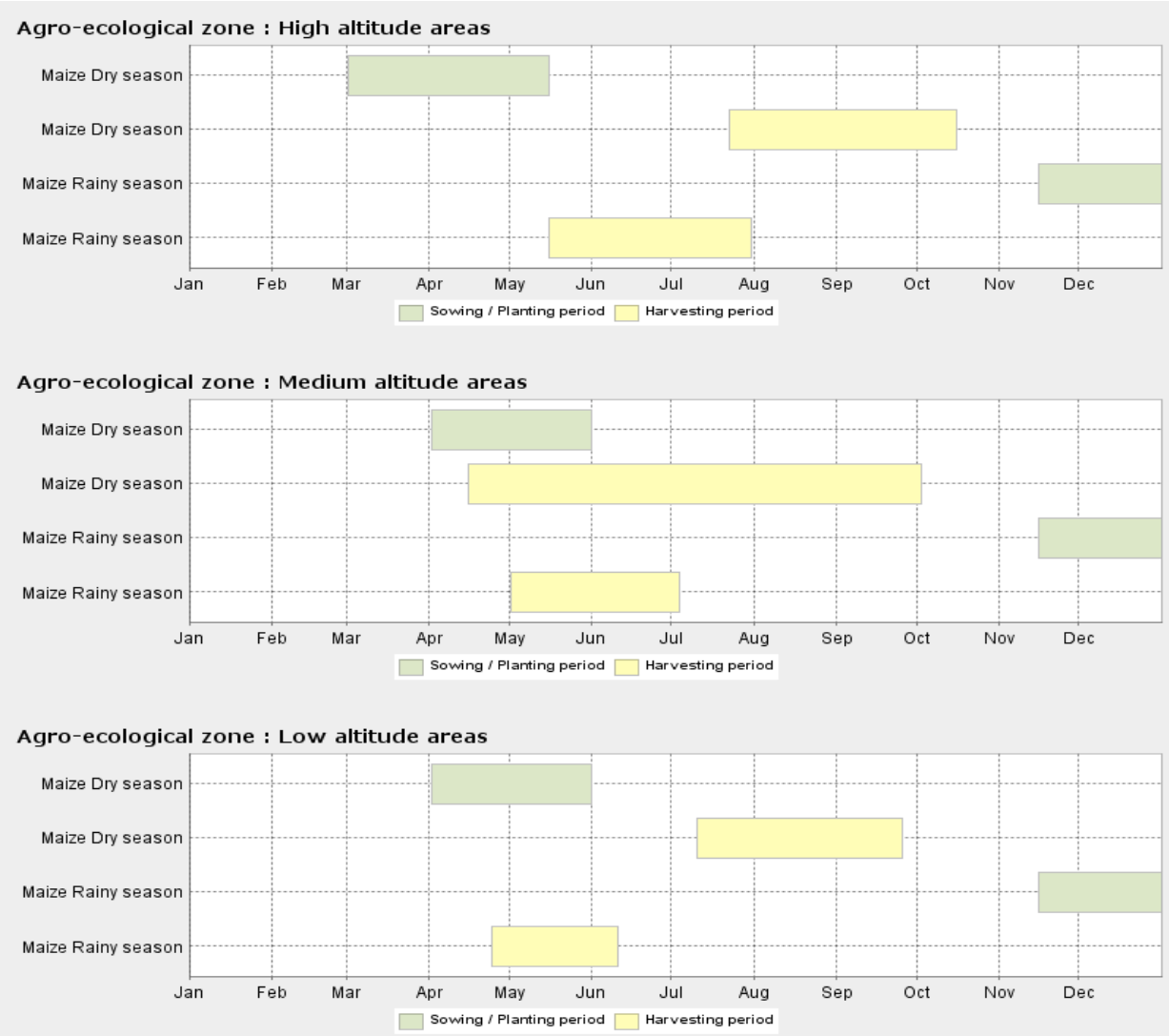
[8] Late planted maize is particularly vulnerable to rust.

2.1.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF MAIZE



- Riley (1981) Planta 151: 68-74
- Ellis RH et al (1992) Crop Science 32:1225-1232.
- Greaves (1996) Journal of Experimental Botany 47 (296): 307-323
- Brown DM (1977) . Agrometeorology of the Maize . World Met Org, Switzerland. No. 481, pp. 15--26

2.1.2 MAIZE: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI



Source: FAO Crop Calendar - http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

2.2 SORGHUM

SORGHUM[9]																								
	Vegetative Stages												Reproductive Stages											
	Seed Germination and Initiation				Emergence and Seedling Growth.				3-and 5-leaf Stages. Root Growth				Growing Point Differentiation and Floral initiation				Culm elongation, bloom stage and Soft-Dough Stage				Hard-Dough Stage and Physiological Maturity			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition[10,11]	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on sorghum productivity[12,13]	+	0	-	-	+	0	-	0	0	-	-	0	+	0	0	0	0	0	-	0	0	0	-	0

[9] Lower Shire Valley (in Southern Malawi) is the main sorghum producing area in Malawi. In that region the rainfall is lower than the rest of the country. Though its production is not significant, sorghum has a high value in drought-prone areas as it can grow in areas that receive less than 650 mm of annual rainfall.

[10] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

[11] In past two decades the Shire Valley has experienced significant weather fluctuations ranging from severe drought conditions (1991-1992) to severe flooding conditions (2000-2001)

[12] Sorghum is a low yielding crop in Malawi, almost one third of that of maize.

[13] It is not a favorite staple crop, falls behind maize and rice.

SORGHUM PESTS AND DISEASES																								
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
SORGHUM PESTS																								
Spotted Stemborer *Chilo partellus*[14]	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
Striga Purple witchweed *Striga hermonthica*[15]	+	0	+	0	+	-	+	0	+	0	+	0	0	+	+	0	0	+	+	0	+	0	0	+
Sorghum Aphid *Melanaphis saccari*[16]	0	0	0	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
Lesser Grain Borer *Rhyzopertha dominica*[17]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0
Angoumois Grain Moth *Sitotroga cerealella*[18]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0

[14] Wind velocity has significant positive correlation with infestation.

[15] hermonthica occurs in general under conditions of low fertility.

[16] Heavy infestations on sorghum at the booting and heading stages critically reduce both grain quality and yield.

[17] Infestations of *R. dominica* adversely affects quantity and quality of stored seed.

[18] It can cause losses of up to 50% during storage.

FUNGAL DISEASES																								
Sorghum downy mildew *Peronosclerospora sorghi*[19]	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Anthracnose *Colletotrichum graminicola*[20]	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Covered kernel smut *Sporisorium sorghi*[21,22]	+	-	+	-	0	0	0	0	0	0	0	0	+	-	+	0	+	-	+	0	+	-	+	0
Rust *Puccinia purpurea*[23]	0	0	0	0	0	0	0	0	0	0	0	0	+	-	+	0	+	-	+	0	+	-	+	0
Leaf blight *Helminthosporm turcicum*[24]	+	-	+	0	+	-	+	0	+	0	+	0	+	0	+	0	0	0	0	0	0	0	0	0
Grey Leaf Spot Cercospora sorghi[25]	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Sooty stripe *Ramulispora sorghi*	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0

[19] Require warm temperatures and high humidity to develop. Found at all stages of growing.

[20] Rain splash can disperse spores within crop canopy. Pathogen persists on and in seed, crop residues. Not as prevalent as mildew.

[21] Caution must be taken at harvest time since galls are broken and spores can contaminate the outer surface of other kernels.

[22] Once inside the seedling, the fungus grows systemically, apparently without damaging the plant until heading development.

[23] Rust control is achieved primarily by cultivating resistant varieties.

[24] Under warm, humid conditions disease may cause serious damage by killing all leaves before plants have matured.

[25] Yield losses of up to 67% have been recorded in some susceptible cultivars.

Zonate Leaf Spot *Gloecercospora sorghi*[26]	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Rough Leaf Spot *Ascochyta sorghi*[27]	0	0	0	0	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0
Oval Leaf Spot *Ramulispora sorghicola*	+	-	+	-	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0

[26] Temperatures ranging from 28 to 32^{0}C are ideal.

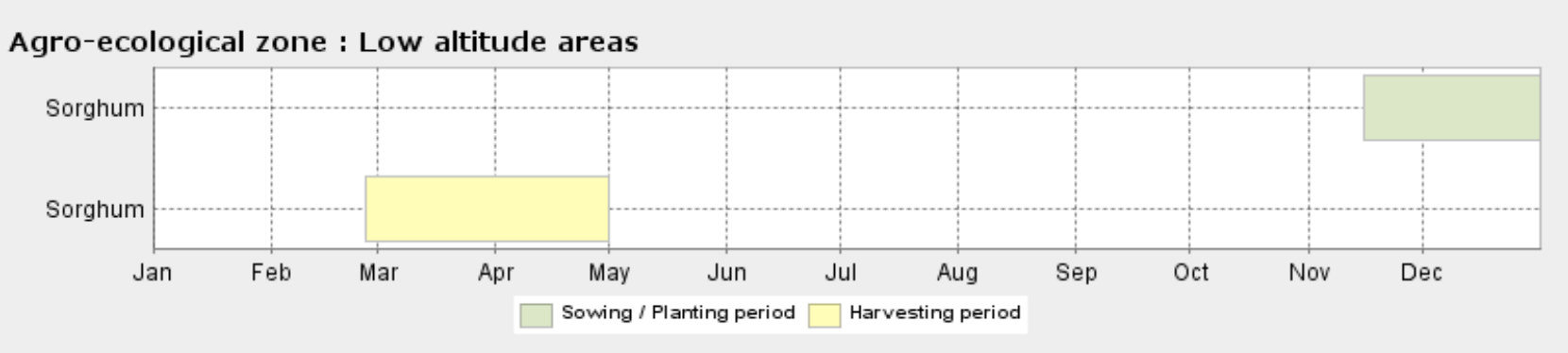
[27] This is more important on sweet sorghum varieties.

2.2.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF SORGHUM

SORGHUM	Seed Germination and Initiation	Emergence and Seedling Growth.	3-and 5-leaf Stages. Root Growth	Growing Point Differentiation and Floral initiation	Culm elongation, bloom stage and Soft-Dough Stage	Hard-Dough Stage and Physiological Maturity	Annual Average Optimal Temperature	Annual Average Optimal Rainfall	
Celsius	Temp	Temp	Temp	Temp	Temp	Temp	Temp		**mm/year**
37									4000
36									3800
35									3700
34									3600
33									3500
32									3400
31									3300
30									3200
29									3100
28									3000
27									2900
26			optimal						2800
25									2700
24									2600
23									2500
22									2400
21									2300
20									2200
19									2100
18									2000
17									1900
16									1800
15									1700
14									1600
13									1500
12									1400
11									1300
10									1200
9									1100
8									1000
7									900
6									800
5									700
4									600
3									500
2									400
1									300
0									200

- du Plessis J (2008) Sorghum Production. Republic of South Africa, Dept. of Agriculture
- Prasad et al. (2008) Crop Sci. 48:1911–1917.
- Peacock (1982) ICRISAT Sorghum in the Eighties: Proc of the International Symposium on Sorghum. 2-7 Nov 81.
- Wortman et al (2008) The Atlas of Sorghum Production in Eastern and Southern Africa. PR189, USAID

2.2.2 SORGHUM: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI



Source: FAO Crop Calendar - http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

2.3 GROUNDNUTS

GROUNDNUTS[28,29]																								
	Vegetative Stages												Reproductive Stages											
	Germination and Seedling Emergence				Stem elongation and Root Development				Stem Growth and Leaf Development				Inflorescence Emergence				Flowering				Pod/Seed Ripening and Harvest			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased[30]	Warmer than normal[31]	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on groundnut productivity [32]	+	-	0	0	0	-	-	-	0	-	-	0	-	0	-	-	0	-	-	-	0	-	-	-

[28] Groundnuts are grown in all parts of Malawi. Rainfall is quite important since many of the areas of cultivation for this crop are rainfed.

[29] Ong CK (1986) Agrometereology of Groundnuts. Proc of an Internat Symp. Aug 21-26, 1985. ICRISAT, India.

[30] Severe water deficit can delay onset of flowering and rapid pod growth.

[31] Pollen death is reported to occur at 33°C.

[32] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

GROUNDNUTS PESTS AND DISEASES																								
	Germination and Seedling Emergence				Stem elongation and Root Development				Stem Growth and Leaf Development				Inflorescence Emergence				Flowering				Pod/Seed Ripening and Harvest			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Yellow Witchweed *Alectra vogelii*[33]	+	-	+	-	+	-	+	-	+	-	+	-	+	0	+	0	0	0	0	0	0	0	0	0
Peanut Pod Nematode *Ditylenchus africanus*[34]	+	0	+	0	+	0	+	0	0	0	+	0	0	0	+	0	0	0	+	0	0	0	0	0
FUNGAL DISEASES																								
Aspergillus flavus[35]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	+	+	0	0	+
Late Leafspot *Cercosporidium personatum*[36] [37]	0	0	0	0	0	0	0	0	+	-	+	-	+	-	+	-	+	0	+	0	0	0	0	0

[33] Yield losses may range from 41% to total crop lost.

[34] Affects the yield of peanut seeds by increasing premature germination.

[35] *A. flavus* is likely to thrive in hot and dry climates. Drought and high temperatures increase severity of the disease.

[36] Cause defoliation, reduced yield, and increased incidence of certain soilborne diseases.

[37] Environmental conditions required for both types of leafspot are warm temperatures and long periods of high humidity or leaf wetness.

Groundnut Rust *Puccinia arachidis*[38]	0	0	0	0	+	-	+	-	+	-	+	-	+	-	+	-	0	0	0	0	0	0	0	0
Leaf Scorch *Leptosphaerulina crassiaca*[39]	0	0	0	0	+	-	-	+	+	-	-	+	+	0	0	+	+	0	0	+	+	0	0	+
Web Blotch *Phoma arachidicola* [40]	0	0	0	0	+	-	-	+	+	-	-	+	+	0	0	+	+	0	0	+	+	0	0	+
Anthracnose *Colletotrichum sp.*[41]	0	0	0	0	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	0	0	0	0
Early Leaf Spot *Cercospora arachidicola*[42]	0	0	0	0	0	0	0	0	+	-	+	-	+	-	+	-	+	0	+	0	0	0	0	0
VIRAL DISEASES																								
Groundnut rosette virus (GRV)[43]	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-	-	+	+	-	0	0	0	0
Sunflower Yellow Blotch Umbravirus[44]	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-	-	+	+	-	0	0	0	0

38 Rain promotes infection of this pathogen.

39 Common during late growing season when air temperatures are cooler.

40 Sometimes develops interaction with *Cercospora.*

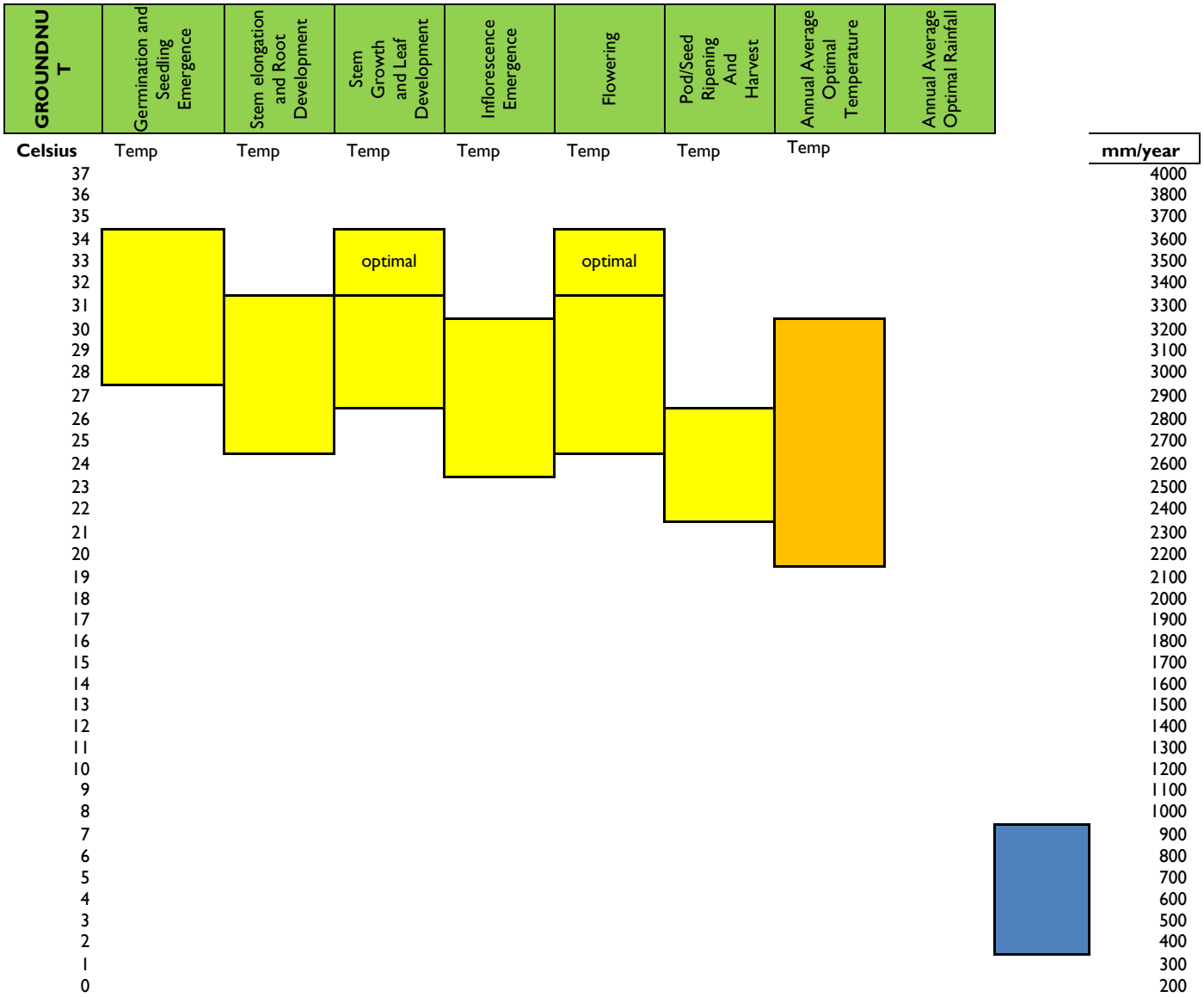
41 *Colletotrichum* can affect stem tips causing die back and stem lesions.

42 Spots first appear on the upper surface of lower leaves.

43 Groundnut Rosette is the most serious virus disease in Malawi, it can cause losses of up to 90%.

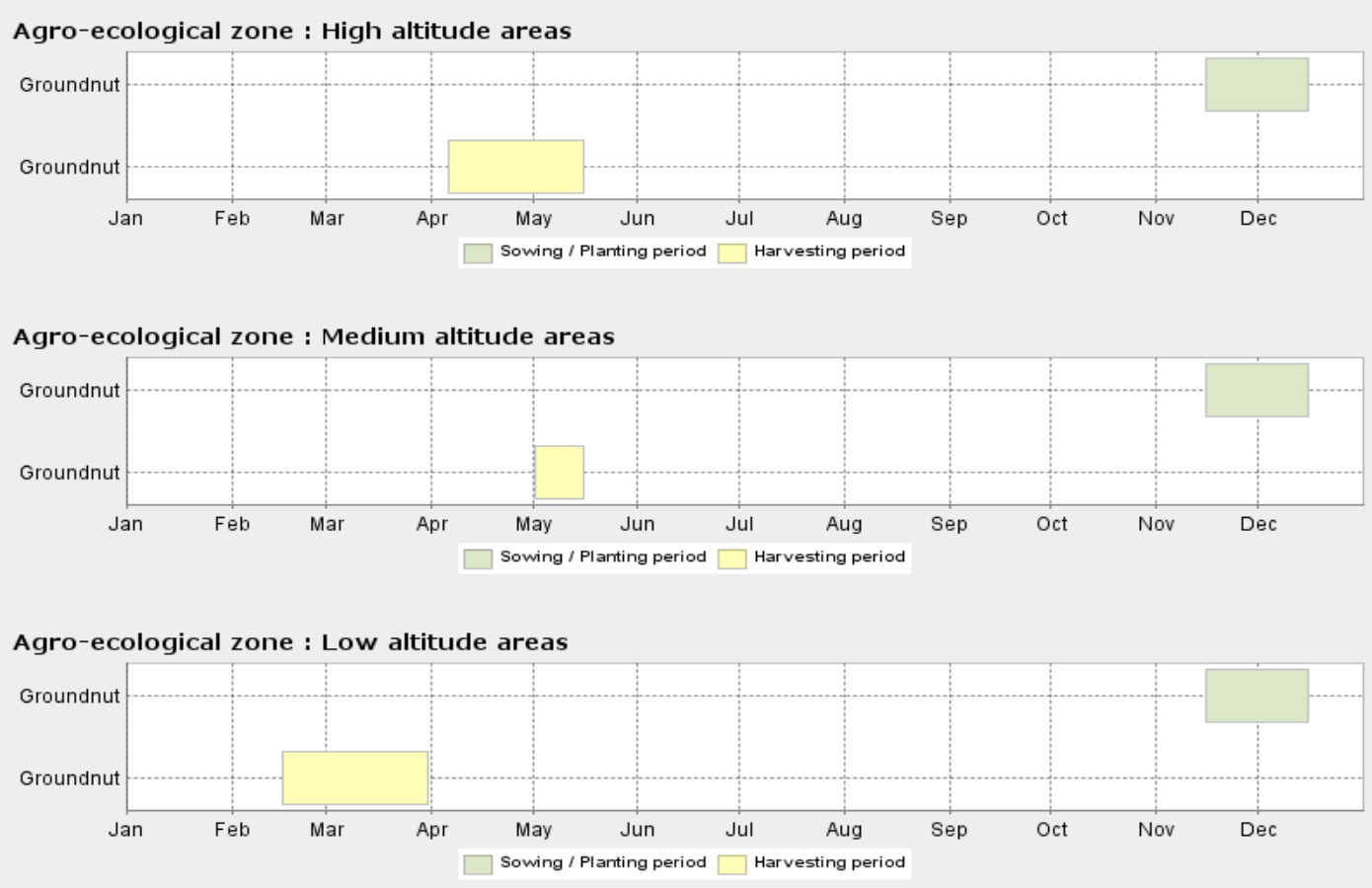
44 Infestation of aphids correlates with virus infection.

2.3.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF GROUNDNUTS



- Ong (1986) Agriclimatological factors affecting phenology of groundnuts. ICRISAT, India
- AJ Cilliers Groundnut Production. A concise guide. ARC Grain Crops Institute
- Ketring and Wheless (1989) Agronomy Journal 81 (6): 910-917.

2.3.2 GROUNDNUTS: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI



Source: FAO Crop Calendar - http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

2.4 PIGEON PEAS

PIGEON PEAS																								
	Vegetative Stages												Reproductive Stages											
	Sowing and Germination				Emergence				Plant growth and maturation				Floral Initiation and Flowering				Grain Filling				Maturity and Harvest Ripe[45]			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal conditions [46]	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on pigeon pea productivity	+	0	+	-	+	0	+	-	+	0	0	0	0	0	0	0	0	-	0	-	0	-	0	-

[45] Seed yield is more sensitive to drought during the reproductive compared to the vegetative growth stage.

[46] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

PIGEON PEA PESTS AND DISEASES																								
	Sowing and Germination				Emergence				Plant growth and maturation				Floral Initiation and Flowering				Grain Filling				Maturity and Harvest Ripe			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
PIGEON PEA PESTS																								
Pod Borer *Helicoverpa armigera* [47]	-	+	+	0	-	+	+	0	-	+	+	0	-	+	+	0	-	+	+	0	-	+	+	0
Bean Pod Borer, Legume Pod Borer, Spotted Pod Borer *Maruca testularis*[48]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	0	+	0	+	0
Pea Blue Butterfly *Lampides boeticus, Catochrysops strado*[49]	0	0	0	0	0	0	0	0	0	0	0	0	+	0	+	0	+	0	+	0	+	0	+	0
Thrips Megalurothrips spp[50]	0	0	0	0	0	0	0	0	0	0	0	0	-	+	+	0	-	+	+	0	-	+	+	0

[47] It is the most important biotic constrain for pigeon peas worldwide.

[48] The borer can infest many alternate hosts.

[49] Risk of infestation is higher in long droughts.

[50] It causes extensive destruction before flowers are produced by feeding on floral buds.

Blister beetle, orange blister beetle [51] *Mylabris pustulata*	0	0	0	0	0	0	0	0	0	0	0	0	-	+	-	-	-	+	-	-	-	+	-	-
Pod Fly *Melanagromyza obtuse*[52]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	+	-	+	-	+	-	+
Sucking Bugs [53, 54]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0
Cutworms *Agrotis spp*[55]	0	+	-	-	0	+	-	-	0	+	-	-	0	+	-	-	0	+	-	-	0	+	-	-
Jassid Leafhopers *Empoasca kerri*[56]	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+
Aphids *Aphis craccivora*[57]	0	0	0	0	0	0	0	0	-	+	0	+	-	+	0	+	-	+	0	+	-	+	0	+
Mites *Aceria cajani*	0	0	0	0	-	+	+	0	-	+	+	0	-	+	+	0	-	+	+	0	0	0	0	0
***Bemisia* whitefly** *Bemisia tabaci*[58]	0	0	0	0	0	0	0	0	-	+	+	0	-	+	+	0	-	+	+	0	0	0	0	0

[51] Rainfall may wash some insects from the plants. Temperature and light intensity influence flight.

[52] Responsible for some of the major damage to the pods.

[53] Sucking bugs include Anoplocnemis spp, Clavigralla spp), Riptortus spp and Nezara viridula.

[54] Periods of drought can trigger infestation by these bugs.

[55] Eaton Eat plants soon after germination at ground levels.

[56] Damage signs include yellowing at the edges of leaves.

[57] They transmit viral mosaic diseases.

[58] Responsible of transmitting viral diseases.

Root-Knot Nematode *Meloidogyne javanica*[59]	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
Root knot nematodes *Meloidogyne spp*	-	+	+	-	0	+	+	-	0	+	+	-	0	+	+	-	0	+	+	0	0	+	+	0
Scales *Icerya purchasi*[60]	-	0	+	-	-	0	+	-	-	0	+	-	-	0	+	-	-	0	+	-	0	0	0	0
Weevils [61] *Myllocerus undecimpustulatus*	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-	-	+	+	-	0	0	0	0
Termites[62] *Microtermes., Ancistrotermes, Trinervitermes Macrotermes Odontotermes*	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
FUNGAL DISEASES																								
Fusarium wilt *Fusarium udum*[63]	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	0	0	0	0
BACTERIAL DISEASES																								

[59] In Malawi, *M. javanica* is the predominant nematode and is found in warmer and drier soils.

[60] Scales suck fluids in the stems.

[61] The larvae of this weevil burrow in the soil.

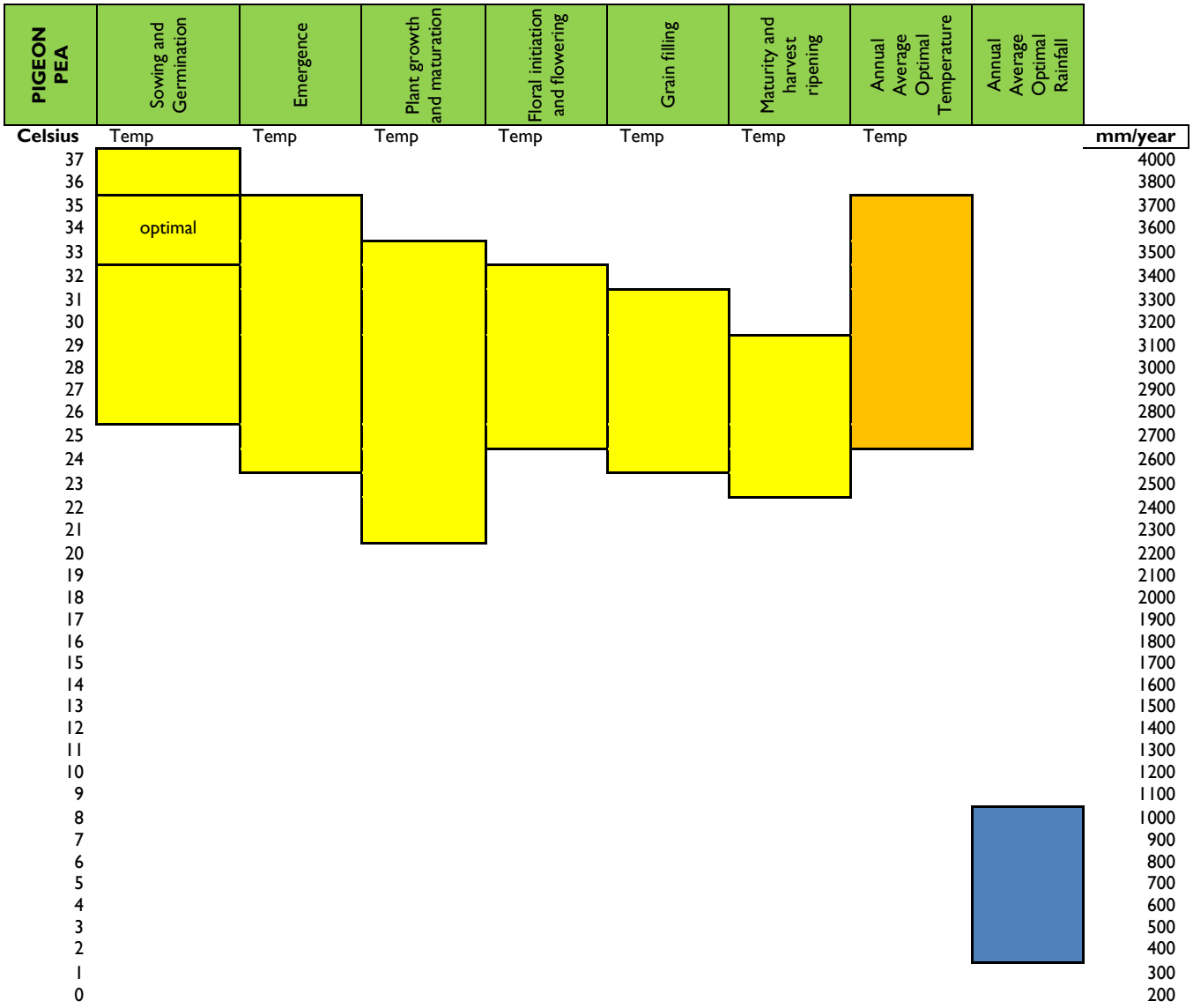
[62] Serious damage is sometimes seen during dry periods or low humidity.

[63] The most prevalent and destructive disease of pigeon pea, yield losses as high as 50-100%.

Leaf spots, stem canker Xanthomonas campestris pv cajani[64]	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-

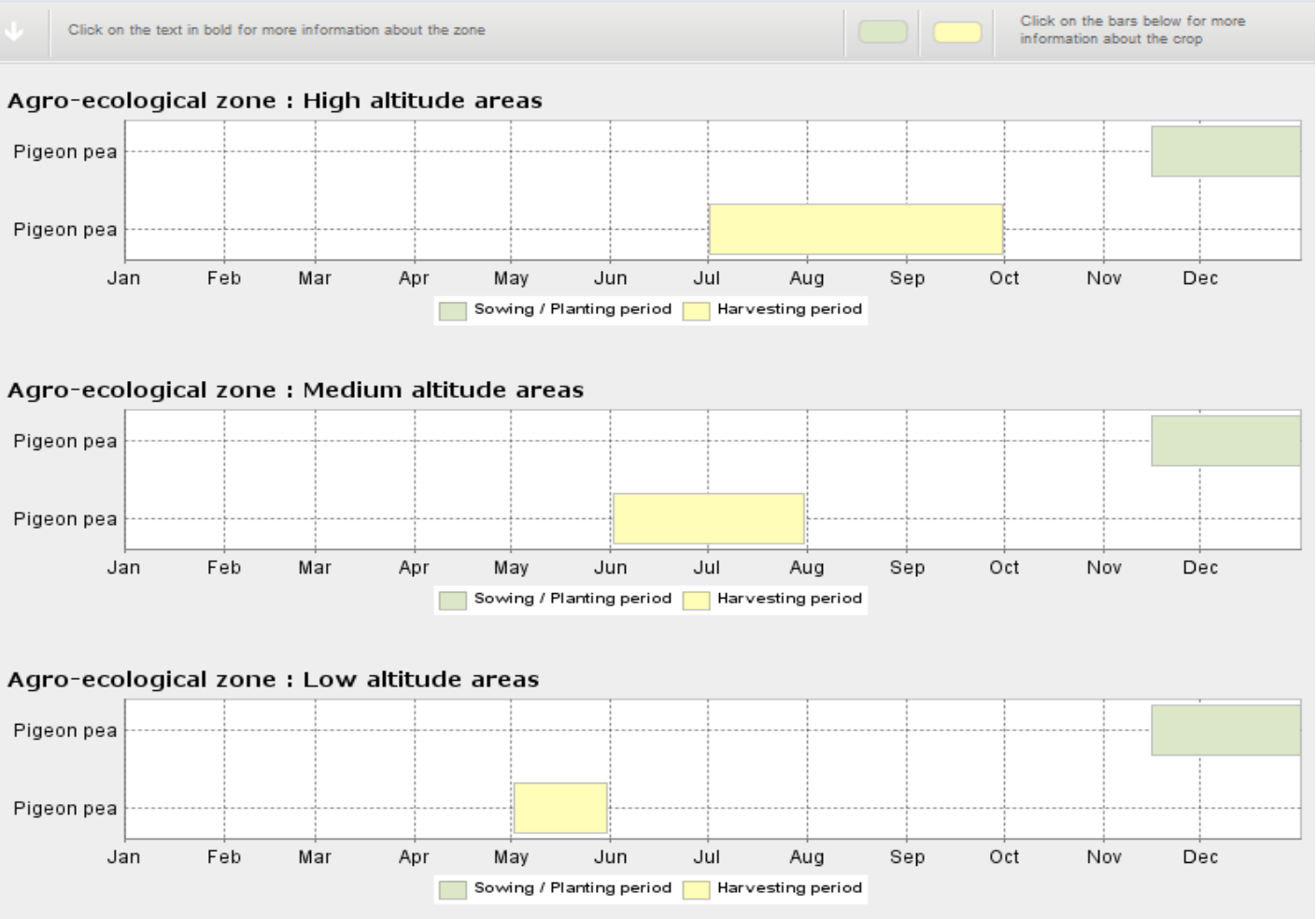
[64] Incidence is higher in low-lying areas

2.4.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF PIGEON PEAS



- Nene et al (Eds) (1990) The Pigeonpea. (CAB International Crops Research Institute for Semi-Arid Tropics, India).
- Sardana Soils, plant growth and crop production. Vol III Growth and Production of Pulses.
- Agrawal SC (2003) Disease of Pigeonpeas. AK Mittal (ed). Concept Pub Company. India
- Omanga and Summerfield (1995) Field Crops Research 41: 25-34.

2.4.2 PIGEON PEAS: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI



Source: FAO Crop Calendar - http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

2.5 COWPEAS

COWPEAS[65, 66]																								
	Vegetative Stages												Reproductive Stages											
	Emergence and Seedling Growth. Root Development				Leaf development and vine growth				Primary branches development				Inflorescence Development, pre-flowering and Flowering				Pod formation				Grain maturation and harvest			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition[67]	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal[68]	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on cowpea productivity	+	-	-	0	0	0	0	0	+	0	-	0	+	0	-	0	+	0	-	0	0	0	-	+

[65] Cowpea has nfootitrogen-fixing properties for improving fertility of soil, so it is good for intercropping. A mean temperature of 27^{0}C is optimum for good pod formation and seed yield. It performs better in regions with annual rainfall of 250-1000 mm (Marfo and Hall, *Crop Science* 3: 912-918, 1992).

[66] Seed shape is a major characteristic correlated with seed development in the pod.

[67] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

[68] Many cowpea genotypes exhibit heat-induced suppression of floral bud development. This damage reduces pod set, number of seeds per pod, and thus seed yield.

COWPEA PESTS AND DISEASES																								
	Emergence and Seedling Growth. Root Development				Leaf development and vine growth				Primary branches development				Inflorescence Development, pre-flowering and Flowering				Pod formation				Grain maturation and harvest			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
COWPEA PESTS																								
Yellow Witchweed *Alectra vogelii*[69]	+	-	+	-	+	-	+	-	+	-	+	-	+	0	+	0	0	0	0	0	0	0	0	0
Cowpea aphids *Aphis craccivora*[70, 71]	0	0	0	0	0	0	0	0	+	0	+	-	+	0	+	-	+	0	+	0	0	0	0	0
White Grubs Coleoptera: Scarabaeidae[72]	+	0	0	+	+	0	0	0	+	0	0	0	+	0	0	0	+	0	0	0	+	0	0	0

[69] Striga witchweed (*S. hermonthica)* is more adaptive to adverse climatic conditions of increased osmotic potential and extreme temperatures than *A. vogelii*.

[70] Cowpea aphid injects a powerful toxin into the plant while feeding and, when populations are large, this can stunt or kill plants.

[71] Cowpea aphids are known to transmit a number of plant viruses.

[72] Infestation is more severe when relatively higher annual rainfall.

Legume Pod Borer, Cowpea Caterpillar *Maruca vitrata*[73,74]	0	0	0	0	+	-	+	-	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0
Cowpea weevil *Callosobruchus maculatus*[75]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	+	+	0
Root-Knot Nematode *Meloidogyne javanica*[76]	+	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0	0	+	+	0
FUNGAL DISEASES																								
Scab *Sphaceloma* sp.[77]	0	0	0	0	0	0	0	0	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0
Cercospora Leaf Spot *Cercospora canescens*[78]	0	0	0	0	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Ascochyta blight *Ascochyta phaseolorum*[79]	0	0	0	0	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0
VIRAL DISEASES																								

[73] Adults are most active during the rainy season.

[74] This is the most important pod borer pest, causing severe damage to cowpeas.

[75] It is the most common and widespread insect pests in storage.

[76] In Malawi, M. javanica is predominant and is found in warmer and drier soils.

[77] Many successive days of wet weather are ideal for the disease.

[78] It is widespread in regions with warmer subtropical and tropical climate.

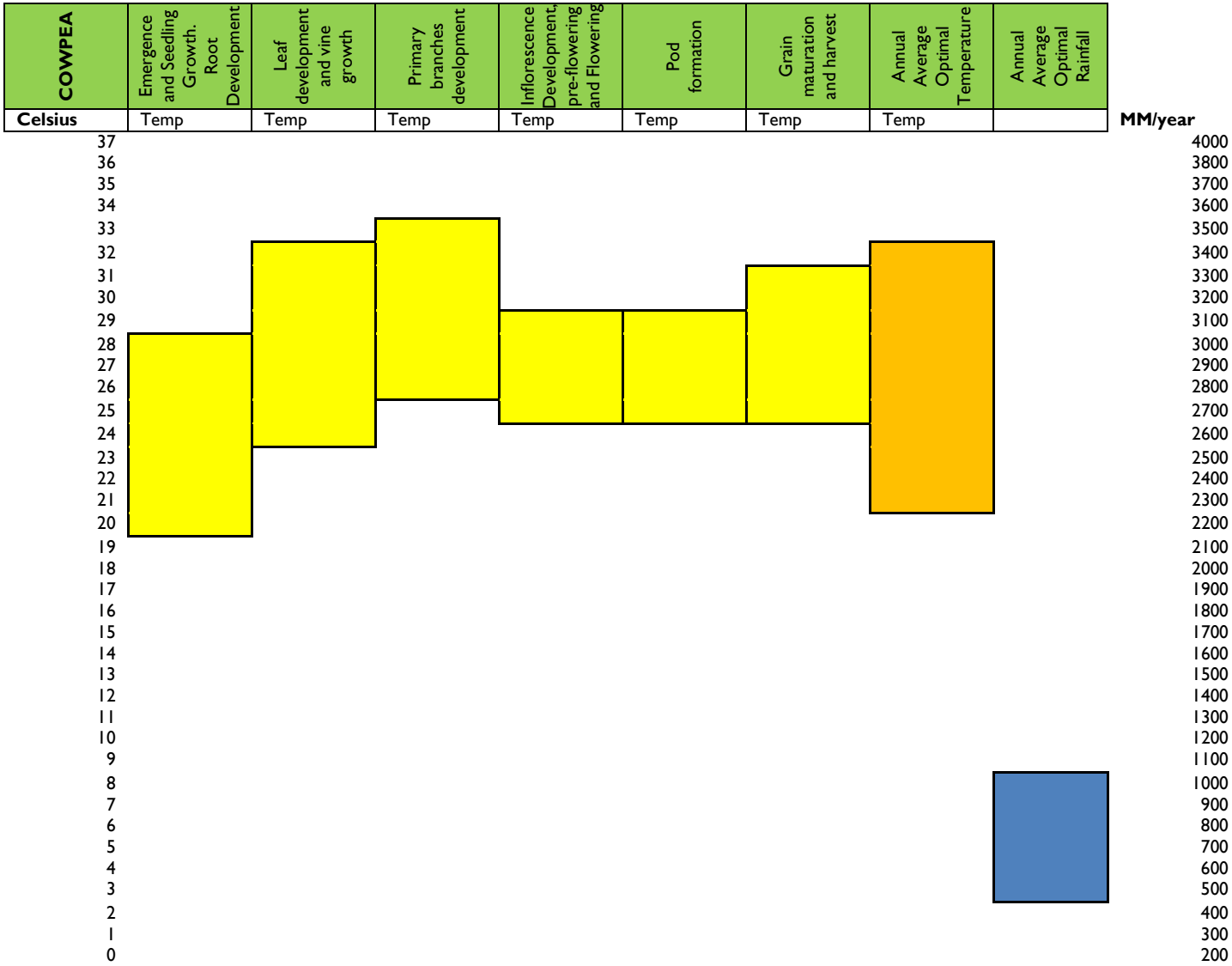
[79] Severe epidemics occur mostly at medium elevations (500-1200 m).

Cowpea Aphid-Borne Mosaic Virus (CABMV) Potyvirus[80,81]	0	0	0	0	0	0	0	0	+	0	+	-	+	0	+	-	+	0	+	0	0	0	0	0

[80] The virus has worldwide distribution and it is considered to be a major and widespread disease of cowpea in sub-Saharan Africa.

[81] *Aphis craccivora* is the most efficient vector.

2.5.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF COWPEAS



- Stewart KA and RJ Summerfield (1978) Plant and Soil49: 443-448
- Warrag (1984) Field Crops Research 8: 3--16
- Ahmed et al (1992) Am Journal of Botany 79(7): 784-791
- Hall AE (1992) Plant Breeding Rev 10: 129–168.

2.5.2 COWPEAS: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI

No agronomic calendar was found for cowpeas in Malawi.

2.6 SOYBEANS

SOYBEANS																								
	Vegetative Stages												Reproductive Stages											
	Seed Germination				Emergence and Seedling Growth				Plant growth and maturation				Inflorescence Development				Flowering				Pod Development and Seed Set			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature[82]		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal conditions[83]	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Impact on soybean productivity	+	0	0	0	+	0	0	0	0	0	0	0	0	0	-	-	0	0	-	0	0	0	0	0

[82] Low and high temperatures can delay flowering. Photoperiod and temperature control the duration of both pre- and post-flowering phases.

[83] Climate projections indicate that mean annual temperature is projected to increase by between 1.2 and 2.5°C or between 1.1 to 3.0°C by the 2060s (using two different climate models). Projections of mean rainfall do not indicate substantial changes in annual rainfall. However, the range of projections from different models is large and includes both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall and increases in wet season rainfall.

SOYBEAN PESTS AND DISEASES																								
	Seed Germination				Emergence and Seedling Growth				Plant growth and maturation				Inflorescence Development				Flowering				Pod Development and Seed Set			
Climatic variables	Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature	
Assumed change from normal condition	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal	Increased	Decreased	Warmer than normal	Cooler than normal
Root-Knot Nematode *Meloidogyne mayaguensis*[84]	+	-	+	-	+	-	+	-	+	0	+	0	+	0	+	0	+	0	+	0	+	0	+	0
Soybean Rust *Phakopsora pachyrhizi*[85, 86]	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Soybean Mosaic Virus Gemini Virus [87]	0	0	0	0	0	0	0	0	-	+	+	-	-	+	+	-	0	0	0	0	0	0	0	0

[84] Rammah, A. and H. Hirschmann (1988) Journal of Nematology20: 58-69.

[85] Ramteke R et al. (2003) J Oilseeds Res 20:195–203.

[86] Soybean rust is the most destructive foliar disease of soybean in recent times.

[87] Symptoms can be difficult to see when temperatures are above 30°C.

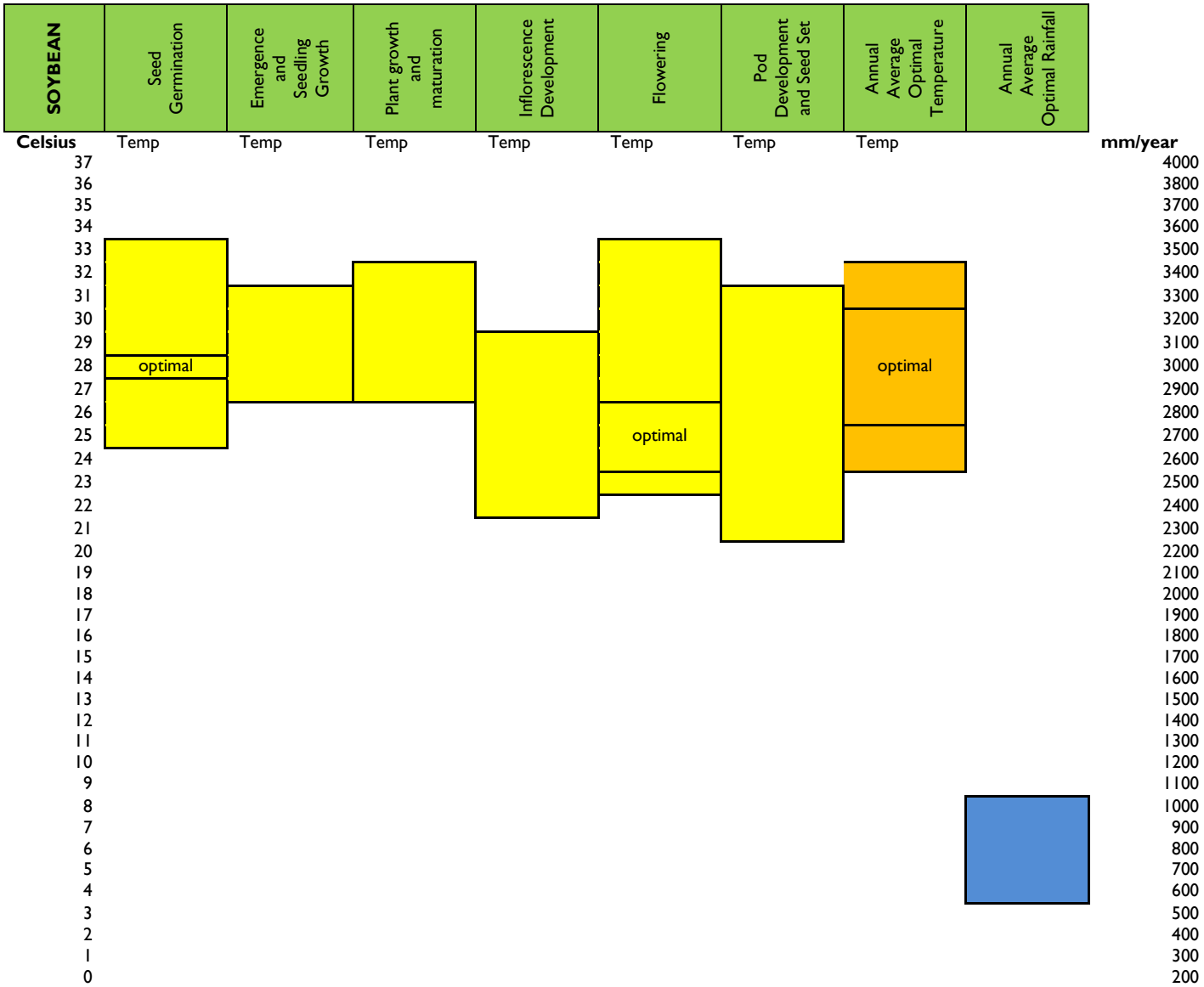
Soybean Red Leaf Blotch *Phoma glycinicola*[88,89]	0	0	0	0	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
Soybean Witches-Broom Disease 16SrII Phytoplasma*[90]	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

[88] Sinclair JB (1989) Plant Disease/73(7): 604-606.

[89] Spread occurs when rain showers, water splash, and/or animal or human activities transport the fungal propagules between plants and fields.

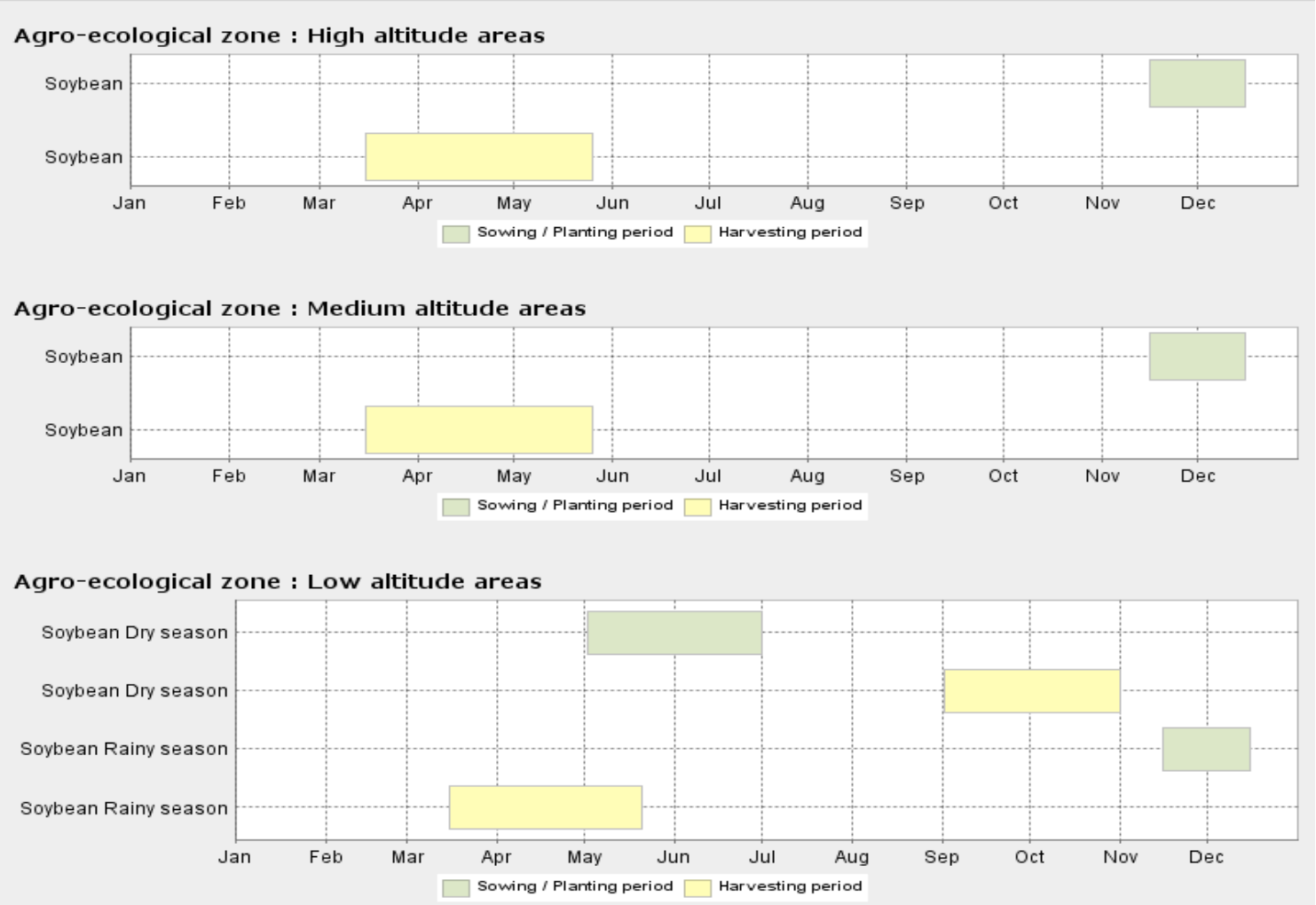
[90] First time reported in Malawi, no information on factors conditioning transmission. Reported in Lava Kumar P and Sharma K (2011) Plant Disease 95(4): 492-493.

2.6.1 TABLE OF OPTIMAL RANGES OF TEMPERATURES AND RAINFALL REQUIRED AT PHENOLOGICAL STAGES OF SOYBEANS



- Kumar A et al. (2008) American-Eurasian Journal of Agronomy 1 (2): 45-50
- SK Tyagi and RP Tripathi (1983) Plant and Soil 74(2): 273-280

2.6.2 SOYBEANS: AGRONOMIC CALENDAR FOR PLANTING AND HARVESTING IN MALAWI



Source: FAO Crop Calendar - http://www.fao.org/agriculture/seed/cropcalendar/welcome.do