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REVIEW PAPER

Climate Change and Population Growth in Timor Leste: Implications for Food Security

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Abstract The climate in Timor Leste (East Timor) is predicted to become about 1.5 °C warmer and about 10 % wetter on average by 2050. By the same year, the population is expected to triple from 1 to 2.5–3 million. This article maps the predicted changes in temperature and rainfall and reviews the implications of climate change and population growth on agricultural systems. Improved cultivars of maize, rice, cassava, sweet potato and peanuts with high yield performance have been introduced, but these will need to be augmented in the future with better adapted cultivars and new crops, such as food and fodder legumes and new management practices. The requirements for fertilizers to boost yields and terracing and/or contour hedgerows to prevent soil erosion of steeply sloping terrain are discussed. Contour hedges can also be used for fodder for improved animal production to provide protein to reduce malnutrition.

Keywords Timor Leste · Climate change · Population increase · Shifting agriculture · Food security · Small-holder farmers

INTRODUCTION

Food insecurity (percentage of households being moderately to severely food insecure) in Timor Leste sits around 64–70 % (Oxfam 2008; Kunwar et al. 2010). Food insecurity is most severe between the months of October and February (WFP 2005; Oxfam 2008) which are the months before the main maize harvest. According to the World Food Programme, chronic and severe malnutrition rates in children were at about 47 and 43 %, respectively (WFP 2005), and may have risen to 52 and 53 % in 2010 (WFP 2010). A primary cause of this food insecurity is poor food availability due to low yields, which average around 1.1 for maize and 1.5 mt ha^{-1} for rice (Oxfam 2008). Agriculture consistently produces less food than is required by the population (WFP 2005) with approximately one-third of cereal requirements being imported (FAO 2010). Low yields in Timor Leste can be attributed to the use of poor-yielding local varieties, poor soils, high weed burdens, steep slopes and highly variable rainfall. Post-harvest grain losses (which decrease food availability) are estimated to be up to 30 % of production (FAO 2007) and is also a major contributor to food insecurity. In order to improve food security in Timor Leste, particularly in light of a rapidly growing population, higher yielding cultivars are needed, soils on sloping lands (and their nutrient content) need to be conserved and improved, rainfall variability needs to be managed, weed impacts lessened and post-harvest losses reduced. When the threat of climate change is added to this already heavy burden, a potentially far more complex situation arises.

Climate change will likely affect the triggers associated with the phenological process of crops (Visser and Both 2005) meaning farmers will have to adapt or change their practices in order to continue farming in the same areas. An increase in variability of rainfall, a shift in the onset of the rainy season and an increase in average temperatures can create a miss-match between crop rainfall requirements at crucial life stages and water availability (Huda et al. 2010), so that the current varieties and species may no longer be able to thrive and will eventually need to be phased out and new crops brought in. Climate change will also likely change the type and extent of crop damage due to disease and the locations in which individual crops can be successfully cultivated. In addition, increased rainfall on the steep slopes of Timor Leste will exacerbate the problem of erosion on the steeply sloping, slash-and-burn managed agricultural lands, while doing little to increase water availability.

This review article addresses the problems of food security in a country with a rapidly expanding population set within a subsistence farming culture, which is constrained by both labour and land and subject to considerable rainfall variability. Climate change will exacerbate these food security issues. The review will (i) provide a background to the new nation of Timor Leste, (ii) report on a current program to improve crop productivity in Timor Leste, (iii) develop climate change scenarios for Timor Leste for 2050 and 2080, (iv) indicate the likely impacts of climate change and population growth on crop production in Timor Leste and (v) suggest changes in agricultural production systems to meet these impacts/challenges.

TIMOR LESTE

Timor Leste is a small country lying between 8.1 and 9.5°S and 125.0 and 127.3°E on the island of Timor, and includes the small enclave of Oecussi between 9.2 and 9.5°S and 124.1 and 124.5°E located in the western half of the island within West Timor (Fig. 1). The island is dominated by a massive central mountainous backbone rising to 3000 m, dissected by steep-sided river valleys. The mountains extend from the centre to the north coast, but on the south side taper off some distance from the coast to provide areas of coastal plain (Phillips 2000). The total land area is 14 874 km^2 (1.5 million ha). Most of the land area has a slope of 8–25 %, and up to 44 % has a slope of >40 % (Barnett et al. 2007).

Due to the changes in elevation and to the orientation north or south of the east–west mountainous spine across the island, six agro-ecological zones, based on their elevation and their north–south orientation have been identified by ARPAPET (1996) and Fox (2003) (Table 1). We also suggest that a zone above 2000 m should be recognized as temperate crops are being grown there. FAO (2007) and WFP/FAO (2003) reports of crop and food supply in Timor Leste indicate that 40 % (600 000 ha) of the land is suitable for crop and livestock production, 12 % (174 000 ha) is arable with an additional 8 % (124 000 ha) of bush gardens. The soils are generally shallow, rocky, alkaline, do not store water well and easily erode (Nunes 2001), but there are small areas of better alluvial soils in the river valleys and flat land along the coasts suitable for cropping. Farming is not restricted to these areas of flat land. While there is little levelling of land, slopes as steep as 40 % are cultivated for crops of maize, cassava, peanut, sweet potato and beans, as well as a broad range of other food crops in home gardens, while small pockets of flat land within the mountains are levelled, puddled and bunded for rice production.

From the middle of the sixteenth century until 1975, Timor Leste was colonised by the Portuguese and then occupied by Indonesia from late 1975. Between 1975 and 1999, about one-third of the population was wiped out (CAVR 2005). In 1999, the large majority of East Timorese voted in a referendum for independence from Indonesia which resulted in unrest, 1400 Timorese killed, 300 000 people moved to West Timor as refugees and the majority of the country's infrastructure and means of production destroyed. In September 1999, an international force was established to end the violence and in 2002 East Timor was internationally recognized as an independent nation. During Portuguese rule, sandalwood *Santalum album* L., a species valued for its oil and perfume, was harvested from the mountain forests for export, leading to deforestation and loss of diversity (McWilliam 2003), while under Indonesian rule encouragement was given to people to clear the forest for crop production. Nevertheless, under Indonesian rule, crop production fell by two-thirds as crops were burnt to starve out guerrillas (Shepherd 2009). The deforestation led to greater runoff and soil erosion on steep slopes (Bouma and Kobryn 2004; Barnett et al. 2007).

The population in 2010 was 1 066 600 and the population density was 71.5 persons per km^2 (National Statistics Directorate 2010). The rural population is considered to be

Table 1 Agro-climatic zones of East Timor, their relative area and the major crops in each zone (adapted from Fox 2003)

Zone (percentage of land area)	Altitude (m)	Rainfall (mm year^{-1})	Length of growing season (months)	Major crops
North coast lowlands (10)	<100	<1000	4–5	Rice, maize, cassava, coconut
Northern slopes (23)	100–500	1000–1500	5–6	Maize, cassava, rice, sweet, potato, cowpea
Northern uplands (19)	500–2000	>1500	6–7	Red beans, coffee, maize, rice, cassava
Temperate uplands (2)	>2000	>2000	9	Potatoes, wheat, barley, arrowroot
Southern uplands (14)	500–2000	>2000	9	Maize, cassava, rice, sweet, potato, cowpea
Southern slopes (21)	100–500	1500–2000	8	Maize, cassava, rice, sweet, potato, cowpea
South coast lowlands (11)	<100	<1500	7–8	Rice, maize, cassava, coconut

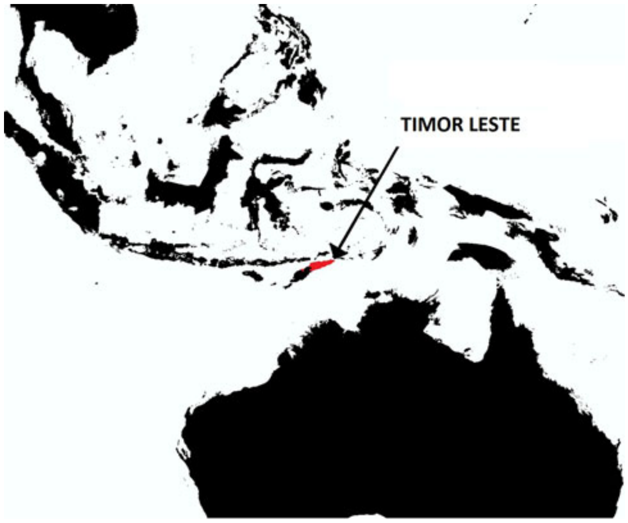

Fig. 1 Location of Timor Leste. The large landmass to the south of the island is northern Australia

about 751 000 (70 % of the total) with 33–74 rural inhabitants per km^2 (National Statistics Directorate 2010). Based on the 2004 census data and with half of the present population under the age of 15, the World Bank (2008) predicted that the population was likely to increase to 1.78 million by 2025 and 2.96 million by 2050 (Fig. 2), leading to a tripling of the population density to 200 per km^2, twice the developing country average (World Bank 2008). The population projections were based on an annual population growth rate of about 3.0 % in 2010, however, the 2010 census indicates that the growth rate has dropped to 2.4 % (National Statistics Directorate 2010), close to the 'slow growth' predictions in Fig. 2. Provided other assumptions do not change, the population is likely to reach 2 500 000, not 3 000 000, in 2050 (World Bank 2008).

Traditional farming systems in Timor Leste have not markedly changed since the early twentieth century. Shifting cultivation and bush-fallow rotations are widely used, particularly in the hills. Shifting cultivation involves clearing and burning natural vegetation, cultivating the cleared area once or twice a year for a season or two, then moving to a new area while the old one regains its fertility under natural regrowth of vegetation (Richards 1985). Near the home, in addition to gardens where squash, tubers and fruit trees are grown, there may be small areas of land that are continuously cropped with maize, cassava, sweet potato and peanut, with animal manures applied to maintain fertility. Level bays are preferably used for rice production (1–3 cycles a year). Chemical fertilizers are not available to most subsistence farmers and as such are not widely used in the majority of traditional cropping systems, however, in 2010 the government began to support the use of chemical fertilizers on rice as a national strategy to boost yields and reduce rice imports. In the majority of the northern farming areas there is only one crop per year as there is only one wet season and one dry season. In the central highlands and on the south coast, the rainfall pattern is bimodal with the two wet seasons usually allowing the planting of two maize crops per year.

The four major food crops are maize, cassava, rice and sweet potato. In 2007–2008, 63 000 ha of maize, 32 000 ha of rice, 12 000 ha of cassava and 5700 ha of sweet potato were grown in Timor Leste (FAOSTAT 2010), with yields of 1.1, 1.5, 4.1, 3.7 and 1 t ha^{-1} for maize, rice, cassava, sweet potato and peanut (with shell), respectively, production in 2008 was 71 500, 60 400, 41 200, 26 000 and

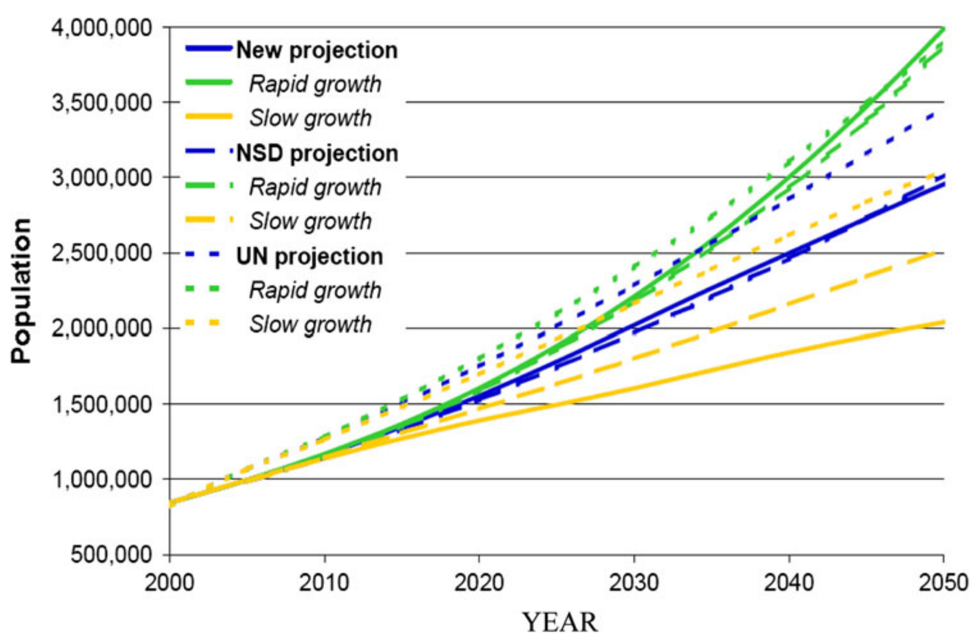

Fig. 2 Projected changes in population in Timor Leste from 2000 to 2050. The World Bank (2008) projections are the *solid lines*, the *long dashes* are the National Statistics Directorate (2005) projections and the *short dashed lines* for the United Nations Population Division (2007) projections; *blue* median projections, *green* rapid growth projections and *yellow* slow growth projections. From World Bank (2008)

4000 t, respectively (FAOSTAT 2010). This was insufficient to meet the food demands of the population so that in 2007 Timor Leste imported 26 500 t of milled rice (in 2009 this figure had increased to 100 000 t), 4000 t of paddy rice, 6000 t of wheat flour, 11 600 t of sugar, 4000 t of dry beans, 1600 t of maize, in addition to small amounts of processed foods such as biscuits and instant noodles. The four major crops provide 1600 kcal person^{-1} day^{-1}, 87 % of the daily calorific intake needed, but only 53 % of the daily protein requirements (this does not include protein from peanuts, the production and consumption of which is difficult to determine as most is stored and eaten on farm) and 22 % of the daily fat requirements (FAOSTAT 2010). These calculations assume that all the production is eaten, whereas the FAO (2007) suggests that one-third of crop production is lost to pests during storage. While overall consumption at 2160 kcal person^{-1} day^{-1} is above the minimum energy requirement of 1800 kcal person^{-1} day^{-1} considered necessary for limited work, this is unevenly spread within the population with 23 % of the population considered undernourished (FAOSTAT 2010) and unevenly spread within the year with the three months before harvest being termed the 'hungry season'. This is particularly serious among children with about 47 % of children under the age of five considered chronically malnourished (stunted) and 43 % severely malnourished (underweight). The rate of wasting (acute malnutrition) is about 12 % nationwide (WFP 2005).

Recent data on poverty in Timor Leste (Datt et al. 2008) show that about half of the Timorese population live in poverty, that poverty is higher in the rural (52 %) than in the urban areas (45 %), is higher in the western and central region (56 %) where the majority of the rural population live, than the eastern region (27 %) and has increased significantly between 2001 and 2007, particularly in the urban areas and in the western and central regions. With 85 % of the population being subsistence farmers on the edge of the cash economy, nearly 80 % of the poor nationally and nearly 90 % of the poor in rural areas depend on the agricultural sector for their livelihood. While the poor participate in the workforce as much as the non-poor, most of the poor are engaged in low-productivity subsistence farming. The poverty index is based on per capita consumption of all food and non-food items, including imputed values of non-purchased items such as those self-produced by the household, rent, gifts and transfers (Datt et al. 2008). As food accounts for 70 % of total consumption, and 81 % if the imputed rent is excluded (Datt et al. 2008), it is clear that increasing the productivity of the agricultural sector would have an important contribution to alleviating poverty. As the 'World Development Report—Agriculture for Development' says "Agriculture is a vital development tool for….halving the share of people suffering from poverty and hunger…through productivity increases in smallholder farming" (World Bank 2007).

From the projected increase in population, the present level of malnutrition, the import of food and low productivity of agriculture, for Timor Leste to be food secure in the future there needs to be a significant increase in agricultural productivity. The 'Seeds of Life' program, in the Ministry of Agriculture and Fisheries in Timor Leste is currently one program that is attempting to meet the present shortfall in food supply.

VARIETAL SELECTION TO IMPROVE CROP PRODUCTIVITY

'Seeds of Life' is a variety evaluation program for Timor Leste that aims to increase crop yields on farm (and therefore reduce the length and intensity of the hungry season), through the use of non-genetically modified, improved crop varieties. The program has been active since the 2000–2001 cropping season. It was set up not only as a response to the loss of seed and planting material during the post-election violence, but also to the loss of Ministry of Agriculture, Forestry, and Fisheries infrastructure following the violence in 1999 (Piggin and Palmer 2003).

Since its inception, 'Seeds of Life' has been testing and introducing new genotypes of the major staple field crops: maize, rice, cassava, sweet potato and peanuts (Borges et al. 2009). These have been supplied by the Consultative Group on International Agricultural Research (CGIAR) crop centres, namely the International Maize and Wheat Improvement Center (CIMMYT), the International Rice Research Institute (IRRI), the International Centre for Tropical Agriculture (CIAT), the International Potato Center (CIP) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). More recently (since 2007–2009) 'Seeds of Life' has added mungbeans and temperate species such as, wheat, barley, potato and climbing bean *Phaseolus* spp. to the varieties being tested. In 2010, the observation of additional species of legumes (pigeonpeas *Cajanus cajan* and wingbeans *Psophocarpus tetragonolobus*) was commenced.

The crop variety evaluations consist of two phases, namely replicated research station trials and unreplicated on-farm trials. Farmers are included at research station field days, in on-farm trials, and in problem-specific on-farm research. Farmers' preferences, from taste tests to suitability of the varieties to their practices and conditions, are therefore part of the steps of the selection process. Approximately 10–20 test genotypes of the major food crops have been grown at four research stations in Timor Leste each year since the 2000 wet season. Many introduced genotypes of maize, peanut, sweet potato, cassava and irrigated rice produced much higher yields than local cultivars or landraces, and some have proved quite acceptable to local growers and consumers. For each crop, several genotypes were broadly adapted with good yields across sites, a result confirmed by the high adoption rates of the varieties by participating farmers (Borges et al. 2009). In order to select 'elite' genotypes for further evaluation on farms, a Farmer Participatory Research approach has been used since 2005–2006. Farmers are invited to field days on research stations at the time of harvest. Here, they evaluate all the genotypes trialled on-station using their own criteria, which can include yield, visual appearance, taste and other qualities (Borges et al. 2009). Based on farmers' preference and yield performance, a small number of the elite genotypes of each food crop are then evaluated on farms.

Farmers, in collaboration with the 'Seeds of Life' research assistants, establish 25 m^2 plots of the elite genotypes among their usual plantings. Management of the plots is completely up to the farmer, with the only request being that the farmers manage each plot in exactly the same way as the rest of their usual plantings. Each year of the on-farm testing component of the program, $\sim$700 on-farm trials are established, with about three quarters of them being successful. The on-farm testing does not end at the harvest of the crop, but continues until the next planting season. In this way, farmers' preferences on qualities such as taste, storability and market acceptance can be evaluated within their own household. By the end of August 2008, seven new crop cultivars have been released. Two of the seven cultivars were yellow maize, three sweet potatoes, one rice and one peanut. At the research station sites, the mean yields over several years of three introduced maize, peanut and sweet potato cultivars and two rice cultivars were from 25 to 140 % higher than the local check cultivar or landrace (Table 2). Except for rice, the mean yields in the on-farm demonstration trials were generally lower than at the research station sites and the yields of the introduced cultivars were not always higher than the local check cultivars (Table 3), but for each crop there was at least one introduced cultivar that gave a yield advantage over many sites and seasons and in the case of sweet potato three of the introduced cultivars had yield advantages of 65–77 % compared with the local cultivar when grown under local farmer management (Seeds of Life 2010a). This well-established protocol and ongoing data collection will form

Table 2 Mean yields and percentage yield advantage of introduced cultivars over the local check cultivar of maize, peanut and sweet potato measured over 4 years (2006–2009) and rice measured over 2 years (2008–2009) at a range of research station sites (adapted from Seeds of Life 2010a)

Crop (no. sites)	Yield (t ha^{-1})				Yield advantage (%)		
Maize (4–6 sites)	Suwan 5	Sele	Har12	Local	Suwan 5	Sele	Har12
	1.7	1.9	1.9	1.1	55	73	55
Peanut (2–6 sites)	Utamua	Pt14	Pt15	Local	Utamua	Pt14	Pt15
	1.5	1.6	1.5	1.2	25	33	25
Sweet potato (1–5 sites)	Hohrae 1	Hohrae 2	Hohrae 3	Local	Hohrae 1	Hohrae 2	Hohrae 3
	15.9	14.6	17.3	7.1	139	106	144
Rice (1–3 sites)		Nakroma	PSB RC80	Local	Nakroma	PSB RC80	
		1.5	1.8	1.3	9	39	

Table 3 Mean yields and percentage yield advantage of introduced cultivars over the local check cultivar of maize, peanut and sweet potato measured over 4 years (2006–2009) and rice measured over 2 years (2008–2009) at a range of on-farm demonstration sites (adapted from Seeds of Life 2010a)

Crop (no. sites)	Yield (t ha^{-1})				Yield advantage (%)		
Maize (170–278 sites)	Suwan 5	Sele	Har12	Local	Suwan 5	Sele	Har12
	2.6	2.4	1.8	1.7	35	41	6
Peanut (6–175 sites)	Utamua	Pt14	Pt15	Local	Utamua	Pt14	Pt15
	1.9	1.1	1.4	1.4	36	−22	0
Sweet potato (83–115 sites)	Hohrae 1	Hohrae 2	Hohrae 3	Local	Hohrae 1	Hohrae 2	Hohrae 3
	5.1	5.5	5.5	3.1	65	77	77
Rice (71–76 sites)		Nakroma	PSB RC80	Local	Nakroma	PSB RC80	
		4.3	3.3	3.4	26	−3	

one aspect of the required response to future climate change and population increase in Timor Leste.

CURRENT AND FUTURE CLIMATE PREDICTIONS

The current level of carbon dioxide (CO_2) in the atmosphere is approaching 400 ppm and is predicted to reach 525 ppm by 2050 and to double in concentration by the end of the present century unless mitigation strategies are widely adopted (IPCC 2007). The observed changes in temperature and precipitation throughout the world over the past three to five decades can be attributed to this increase in the concentration of greenhouse gases in the atmosphere. The Intergovernmental Panel on Climate Change (IPCC) in its fourth report (Christensen et al. 2007) predicted that regional average temperatures and precipitation, based on 21 global models, for the South-East Asia region (20°N, 115°E to 11°S, 95°E) that includes Timor Leste, had a 50 % probability of increasing over the next century (from 1980–1999 to 2080–2099) by 2.5 °C and 6 %, respectively. However, as Timor Leste is a small island, the projections for the islands in the South Pacific region (0°S, 80°W to 55°S, 150°E) may be more appropriate. For this region, the models predict a 50 % probability of a 1.8 °C rise in temperature and a 6 % increase in rainfall (Christensen et al. 2007). However, as coupled atmosphere–ocean global circulation models do not have sufficiently fine resolution to see small islands such as Timor Leste, these projections by the IPCC are given for ocean surfaces rather than over land (Christensen et al. 2007). Barnett et al. (2007) used nine different models from the Commonwealth Scientific and Industrial Organisation (CSIRO) and the IPCC to predict that temperatures in Timor Leste will increase by 0.3 to 1.2 °C by 2030 and 0.8 to 3.6 °C in 2070, while by 2070 rainfall will change by ±20 % in the wet season (November to April) and small increases to large decreases in rainfall in the second wet season (May to July) in the south of Timor Leste and in the dry season (August to October) throughout Timor Leste. The data suggest wide uncertainties in both temperature and rainfall, particularly rainfall, and the authors concluded that the models may not simulate the bimodal rainfall distribution adequately (Barnett et al. 2007). During the writing of this article, Kirono (2010) published a brief overview of the future climate projections for Timor Leste, but the study used observed climate variability and climate trends from studies in Indonesia, Australia and Asia as proxies for Timor Leste. Moreover, the grid size for the projected climate change was large (typically 100–500 km, 'downscaled' to 60 km in some cases) and the authors concluded that there is a need to develop and analyse results from fine-resolution models over Timor Leste (Kirono 2010).

To improve the predictions of climate change in Timor Leste, the current (~1950–2000) rainfall and temperature data were downloaded from the WORLDCLIM dataset (~5-km spatial resolution) (Hijmans et al. 2005) and mapped with DIVA-GIS (Hijmans et al. 2001). The precision and accuracy of the splining calculation were tested by comparing the location-specific output data obtained from WORLDCLIM with the same 26 sites for which there are 20 years (1954–1974) of observations of mean monthly temperature and rainfall. The comparison (Fig. 3) showed that the monthly data interpolated by WORLDCLIM represented the observed values at these 26 highly variable (in temperature, rainfall and elevation) sites throughout Timor Leste well. The interpolating technique utilised by Hijmans et al. (2005) processes thousands of observed data sets and their geographical data to generate a continuous splined, $5 \times 5\,km^2$ pixel output across the globe; it does not output observed data into the maps. While the output data is still not completely independent of the historical observed data, the extent of separation between the inputted data and the output maps and the high correlation between the two indicates that the calculated data from non-observed locations is also useful. The changes in temperature and rainfall for 2020, 2050 and 2080 were then calculated using the A2A scenario (mid-range emissions scenario), a 2.5 arc min (4.65 km at the equator) resolution and the four models (CSIRO, CCMA, HADLEY and CCM3) in the WORLDCLIM database with the visualisations mapped with DIVA-GIS (see also Turner et al. 2011).[1] As all four models predicted a similar increase in temperatures and three of the four models, including the CSIRO model predicted a small increase in rainfall to 2050 (Seeds of Life 2010b), only the predictions and visualisations from the CSIRO model are presented in this review.

Current (~1950–2000) mean annual temperatures vary from 25 to 27.5 °C close to the coast to 15–17.5 °C at the highest elevation in the central mountain range (Fig. 4a). By 2050, the mean temperature is predicted to increase by 1.25–1.75 °C (Fig. 4c) so that temperatures near the coast are predicted to increase to 26.25–29.25 °C, while mean temperatures in the mountains do not decrease below 17.5 °C (Fig. 4b). By 2080, temperatures are predicted to have increased by 2.25–2.75 °C throughout Timor Leste, so that temperatures near the coast are predicted to reach 27.25–30.25 °C (Seeds of Life 2010b). The current annual rainfall varies from <800 mm at a few locations on the north coast to 2400–2600 mm at locations in the mountains (Fig. 4d). By 2050, mean annual rainfall is predicted to increase by 100–120 mm near the coast to 260–280 mm in the mountains and 300 mm at the highest peaks (Fig. 4f). By 2050, all areas will receive an ~10 % additional

[1] (www.worldclim.org/futdown.htm).

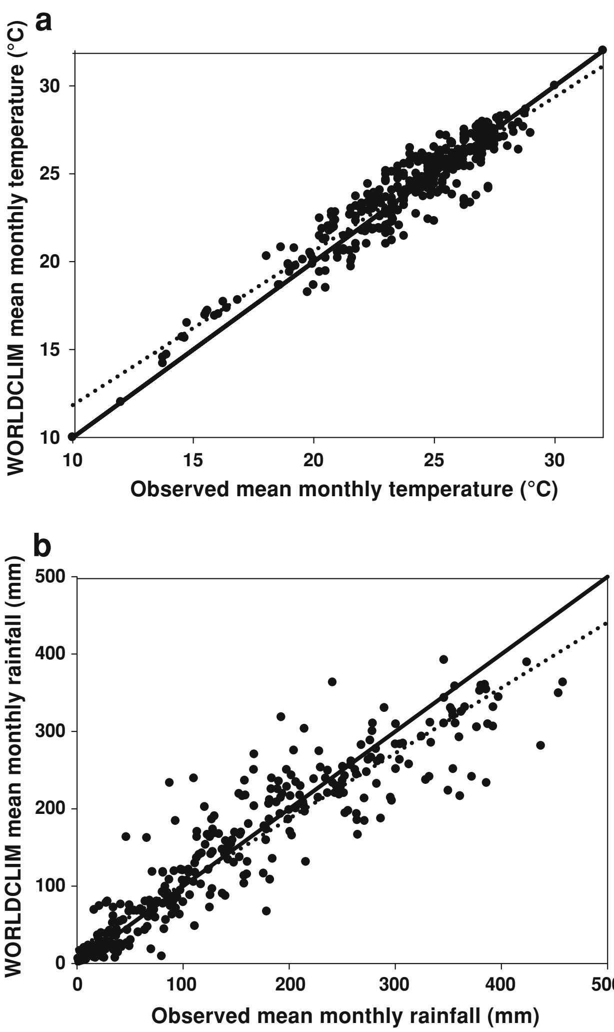

Fig. 3 Interpolated current (~1950–2000) **a** mean monthly temperature and **b** monthly rainfall from the WORLDCLIM database compared to observed values at 26 sites in Timor Leste for which data is available for 20 years from 1954 to 1974. *Solid line* The 1:1 relationship and *dotted line* the fitted linear regression

rainfall. By 2080, rainfall is predicted to increase by about a further 5 % (Seeds of Life 2010b).

The model predicts that there will be no seasonal differences in the rise in temperature by 2050. When the temperatures for 2050 were plotted on a monthly basis throughout the year for six sites across Timor Leste, all sites showed a fairly uniform increase in temperature of about 1.5 °C above the current temperature (Fig. 5). Mean monthly temperatures throughout Timor Leste vary by only 2–3 °C seasonally (coolest in July, warmest in October) and the temperature increase with climate change was similar in all months at each location (Fig. 5). There is considerable evidence that temperatures ≥35 °C affect seed set in a range of species (Turner and Meyer 2011). Therefore, we plotted the number of days ≥35 °C (max daily temperature)against the mean monthly maximum temperature at the hot coastal locations of Dili, Manatuto (north coast) and Betano (south coast) and observed an exponential increase in the number of days ≥35 °C as the mean maximum temperature increased above 32 °C (Fig. 6a). Figure 6a also shows that the frequency of days ≥35 °C increases from less than one to four as the mean monthly maximum temperature in the coastal areas increases from current values of 32.5 °C to predicted values in 2050 of 34.0 °C and to 8 days per month when the mean maximum reaches 35 °C in 2080. Analysis of the length of consecutive days ≥35 °C in Timor Leste suggests that as the mean monthly maximum temperature increases, the length of heat waves ≥35 °C increases exponentially, so that as the mean maximum temperature increases from 32.5 to 34 °C as predicted for 2050, the length of consecutive days ≥35 °C increases from 2 to 4 days (calculated across consecutive monthly boundaries). If the mean monthly maximum temperature increases to 35 °C as predicted for 2080, the length of heat waves will increase to 12 days (calculated across monthly boundaries) (Fig. 6b).

Mean monthly rainfall varies from near 0 mm in the dry season (August to October) to a peak in January and February of almost 400 mm at the highest location (the village of Hatu Bailico). When the predicted mean monthly rainfall for 2000 for the same six sites as for temperatures shown in Fig. 5 were compared with the predicted mean monthly rainfall for 2050, all sites share a common trend of a visible increase in January and February rainfall by 2050 (up to just over 500 mm in Hatu Bailico), but the same or slightly less rainfall in March and April. Those that currently show a second peak in rainfall in May appear to receive a slight increase by 2050, leading to a slightly stronger bi-modal wet-season pattern. This is most obvious in Viqueque, which sees an ~35 % increase in January and February, and a 10 % increase in May (Seeds of Life 2010b). Analysis of the number of consecutive days per month when rainfall is <1 mm (a measure of a dry spell) during the growing season showed that the number increased exponentially as the rainfall decreased below 300 mm month^{-1} (Fig. 6c). The incidence and length of dry spells is greater in the low rainfall areas near the coast. The increase in rainfall is likely to reduce the length of dry spells in average years. However, the inter-annual variation in rainfall is about 30 % over all sites measured between 1960 and 2000 (Fig. 7), with greater variation at the drier coastal sites where maize production is marginal. The frequency and length of dry spells in some years is therefore still likely to be significant for farmers in coastal regions. The increase in rainfall bimodality at certain sites, if expressed not only through rainfall increases but also decreases during the months of March and April, may increase the likelihood of dry spells at these times. Nevertheless, the mean increase in rainfall between now and

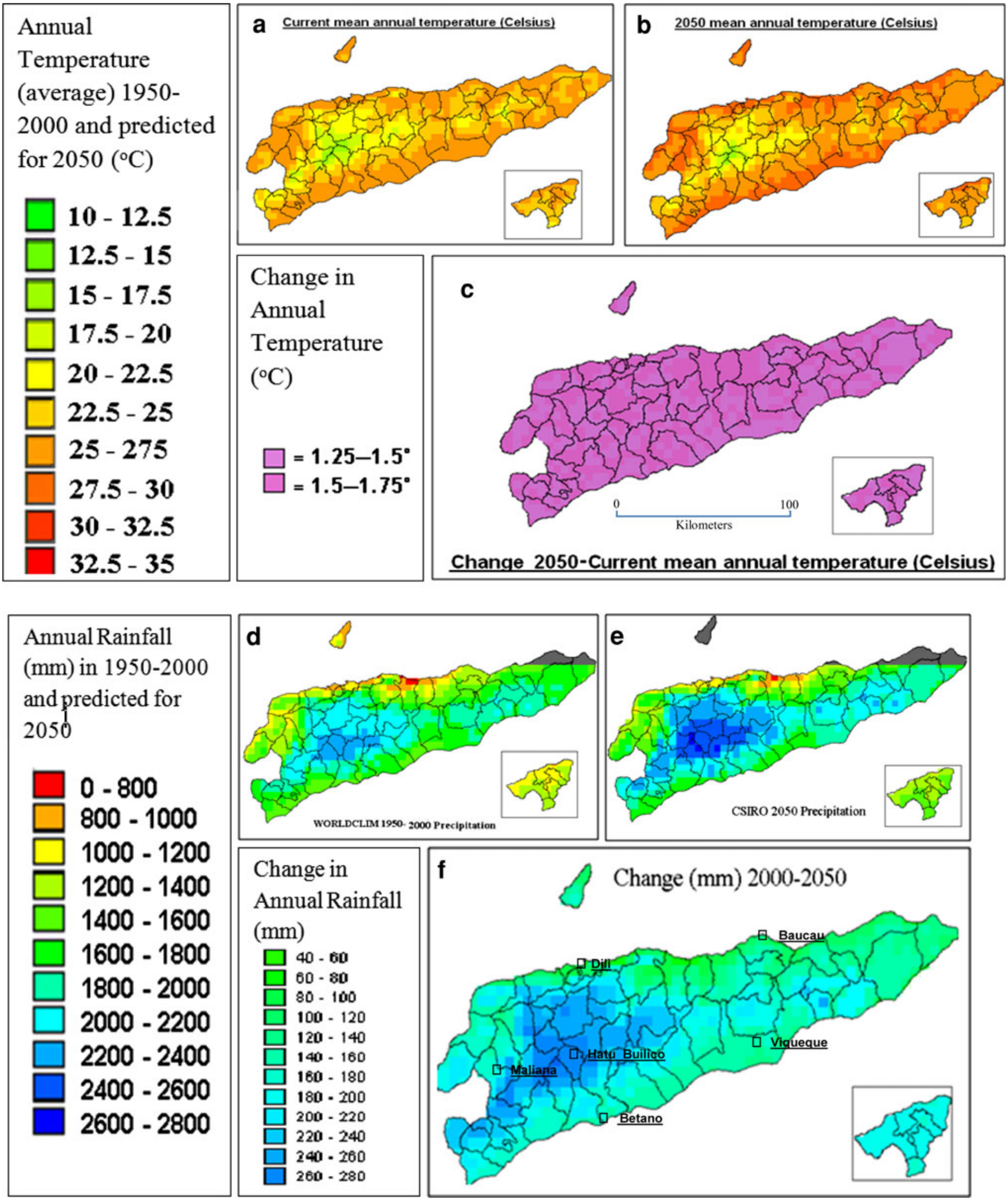

Fig. 4 The current (∼1950–2000) (**a**, **d**), predicted for 2050 (**b**, **e**) and the difference between 2050 and current (**c**, **f**) mean annual temperatures (**a**–**c**) and rainfall (**d**–**f**) for Timor Leste. The *inset* is for the Timor Leste enclave of Oecussi in West Timor. The values of temperature change have been grouped into one band and colour (1.25–1.75 °C). This was because there was no spatial pattern or difference between areas across the country that justified separation or identification. The current values were obtained from the WORLDCLIM database and 2050 predicted values were for the A2A scenario of the CSIRO model in the WORLDCLIM database (www.worldclim.org/futdown.htm). The change maps were drawn using the DIVA-GIS programme

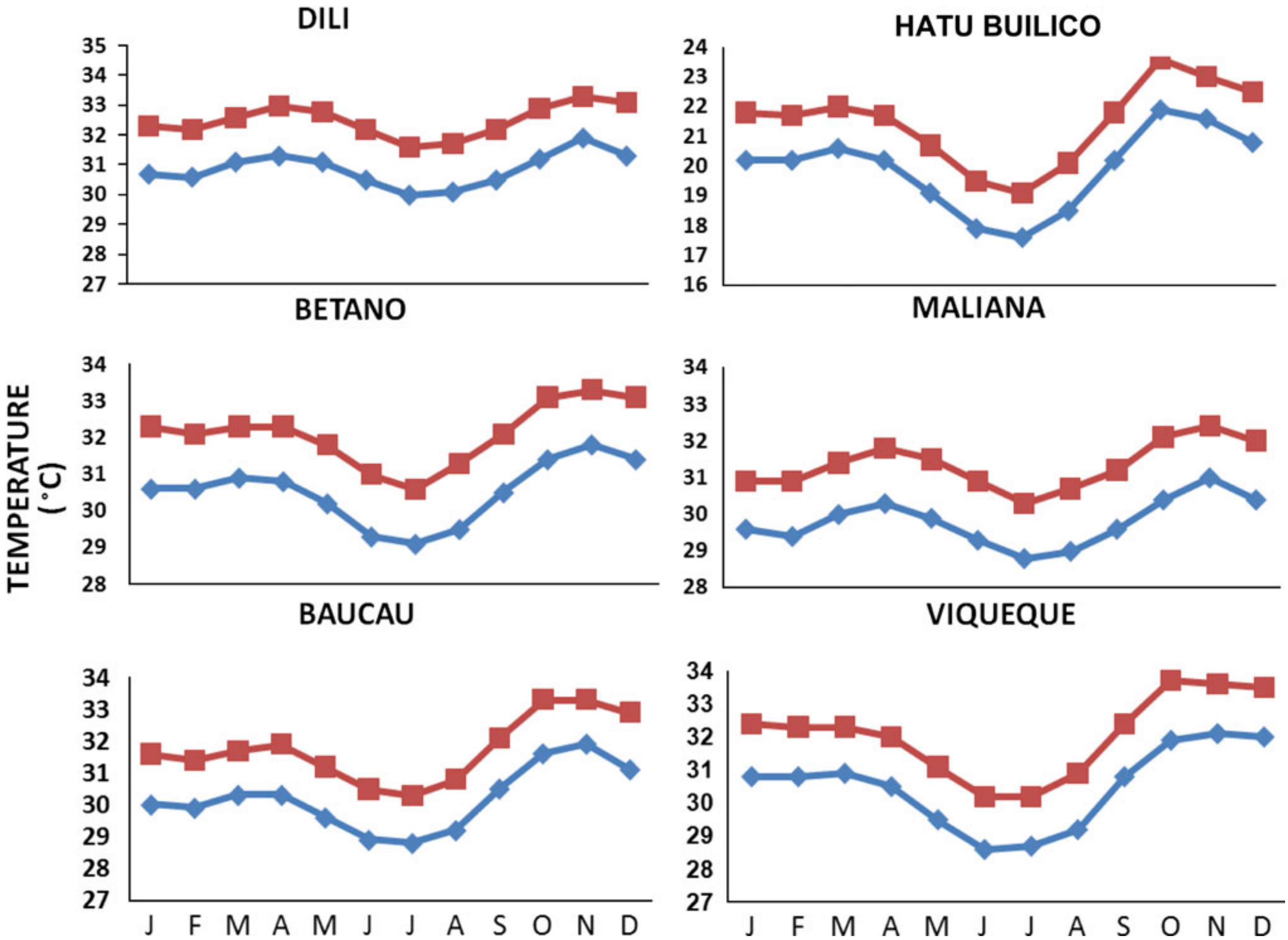

Fig. 5 The current (~1950–2000) mean monthly temperatures interpolated from the WORLDCLIM database (*blue symbols* and *lines*) and mean monthly temperatures predicted for 2050 (*red symbols* and *lines*) for six sites in Timor Leste at different locations and elevations. The 2050 predicted values are for the A2A scenario of the CSIRO model in the WORDCLIM database (www.worldclim.org/futdown.htm)

2050 will be less than the inter-annual variability that farmers are currently experiencing (Fig. 7). Thus, some aspects of future climate change should not be regarded as purely contemporary issues that require completely new solutions, but rather can be seen as continuations or intensifications of problems that are already being addressed in current farming practices.

In summary, by 2050 temperatures are predicted to rise modestly (about 1.5 °C) at all elevations and all locations, while rainfall will increase by about 10 % as a yearly average. The increase in temperature, while modest compared to global hotspot predictions of 5.5 °C (90 % of terrestrial locations will experience a greater increase than 1.5 °C), is likely to increase the number of extreme temperatures (days > 35 °C) per month and the length of heat waves in the coastal areas of Timor Leste. While the frequency of cyclones in Timor Leste is low at 0.2 cyclones per year (Kirono 2010), increasing greenhouse gases are expected to alter the hydrologic cycle. Along with other recent predictions, Kirono (2010) suggests that in future the frequency of cyclones and extreme rainfall events in Timor Leste are likely to decrease, but the intensity of the cyclones (with high wind speeds) and extreme rainfall events will increase.

IMPACT OF CLIMATE CHANGE ON CROPPING SYSTEMS

The increase in CO_2 is likely to benefit growth in C_3 crop species such as rice, sweet potato and peanuts, but not C_4 crops such as maize, through the so-called 'CO_2 fertilization' effect. There are, however, negative indications for crops either directly due to the increased CO_2 as well as from associated change such as temperature. When the influence of a doubling of CO_2 on peanut in Africa was evaluated in a modelling exercise, Cooper et al. (2009) showed that increasing CO_2 increased yields by an average

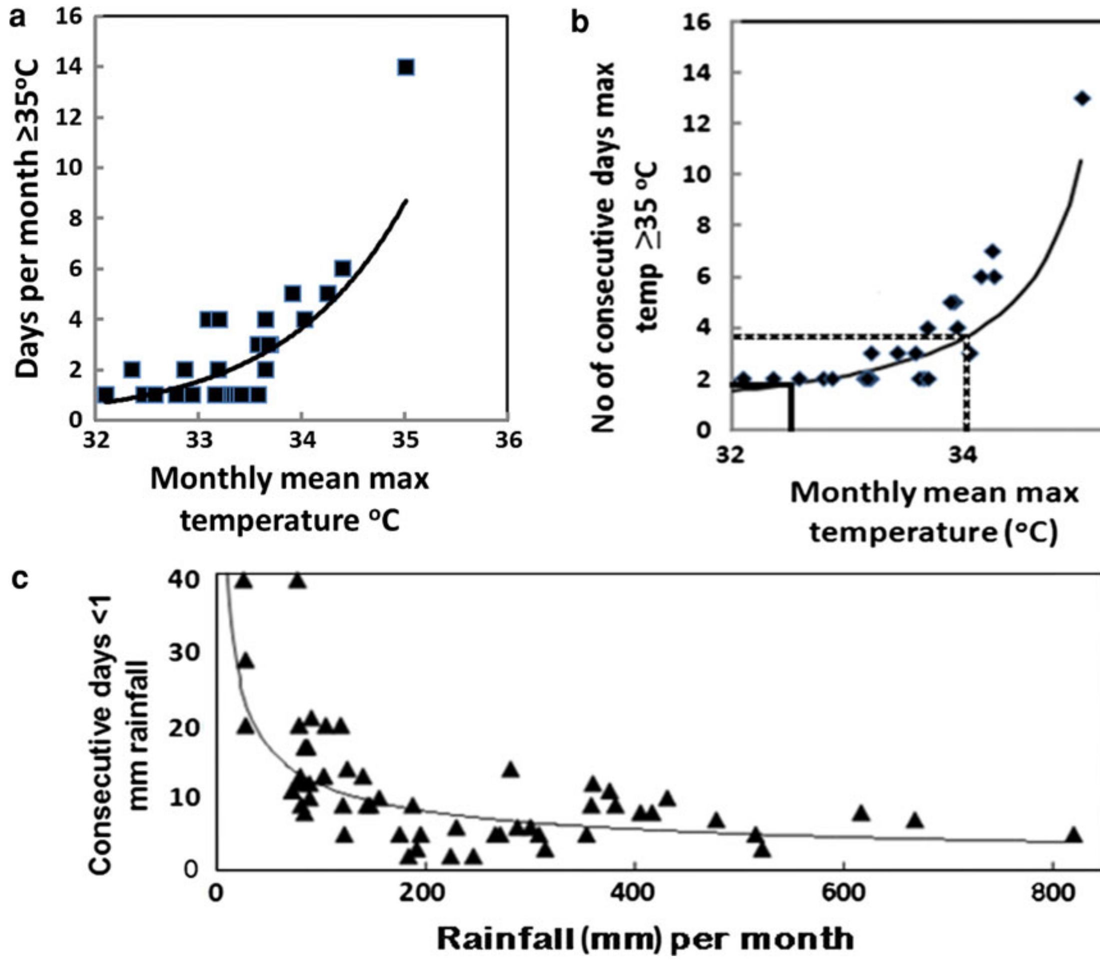

Fig. 6 Number of days per month ≥35 °C (**a**) and consecutive days ≥35 °C per month (**b**) as a function of the mean monthly maximum temperature, and measured number of consecutive days ≤1 mm per month in the rainy season as a function of mean monthly rainfall (**c**) for locations in Timor Leste where more than 20 years of data (1954–1974) are available. The fitted exponential regressions are shown as *solid curves*. The days ≥35 °C and the number of consecutive days ≥35 °C for the current mean temperature (32.5 °C—*solid line*) and that predicted for 2050 (34 °C—*dashed line*) for the sites where measurements were obtained are shown in **a** and **b**. Consecutive days were calculated across month boundaries and averaged to give per month numbers of days

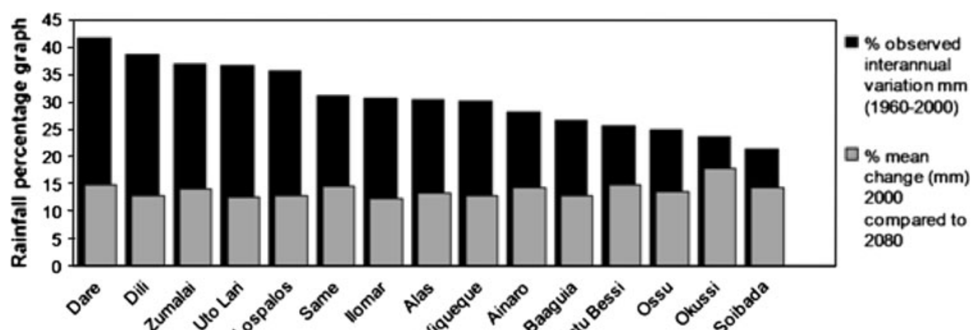

Fig. 7 Measured percentage inter-annual variation in rainfall between 1960 and 2000 at 16 sites in Timor Leste (*solid bars*), and percentage mean change in precipitation between current (∼1950–2000) and predicted rainfall in 2080 (*gray bars*). From Seeds of Life (2010a)

of 7.3 %, compared with a decrease in yield of 35 % from a 3 °C increase in temperature. Ludwig and Asseng (2006) showed that the increase in wheat yields due to increasing CO_2 was greater in water-limited environments and at high soil nutrient availability. There were interactions among increases in CO_2, temperature and rainfall for wheat production. Higher temperatures and lower rainfall can reverse the yield increases in wheat arising from higher CO_2 in some soils (Ludwig and Asseng 2006). Further, doubling CO_2 has be shown to drastically reduce the size of cassava tubers while increasing the toxicity of its protein-rich leaves (Gleadow et al. 2009).

While recognising that there are interactions among CO_2, temperature and water status, if no changes of cultivar or management are implemented, rising temperatures in sub-tropical and semi-arid regions are generally expected to decrease yields (Turner and Meyer 2011). The rate of development of a crop is linearly dependent on the cumulative air temperature (growing degree days) above a base temperature which varies with species. Higher temperatures shorten the time to flowering and maturity in photoperiod-insensitive crops, until an optimum temperature is reached above which time to flowering increases with increasing temperature (Cooper et al. 2009). The increase in temperature of 1.5 °C will increase the rate of leaf development, reduce the number of leaves and leaf area, reduce radiation interception, bring forward the time of flowering and maturity and reduce yields (Visser and Both 2005; Cooper et al. 2009; Howden et al. 2010; Vadez et al. 2011; Turner et al. 2011). Using a modelling approach to estimate the effect of increasing temperatures on maize and peanut development and yield, Cooper et al. (2009) showed that each 1 °C increase in temperature above the current decreased the time to maturity of maize by 5 days and decreased yields by 4 % (Table 4). While these data are for maize in Kenya, yields are in the same range as those in Timor Leste, so using the same relationship suggests that a 1.5 °C rise in temperature will decrease the days to maturity in maize by 7.5 days and decrease yields by 6 % (66 kg ha^{-1} from a median yield of 1100 kg ha^{-1}). For peanut, a 1.5 °C rise in temperature will decrease the days to maturity by 12 days and decrease yields by 19 % (190 kg ha^{-1} from a median yield of 1000 kg ha^{-1}). As rainfall is predicted to increase by 10 % by 2050 compared to the current rainfall, we conclude that provided the rainfall distribution does not change, the small increase in rainfall will have little effect on yields. Thus from this analysis, the effect of climate change is likely to have only a minor effect on maize yields, but could significantly decrease peanut yields. There is also the potential for higher temperatures to affect the major cash crop in Timor Leste, coffee. The coffee cultivar grown in Timor Leste, HDT, is a natural hybrid discovered in Timor between Robusta *Coffee canephora* and Arabica *Coffee arabica* coffee species, Robusta species have a higher temperature tolerance than Arabica species. Research needs to be conducted to determine whether HDT exhibits its Robusta genetic tolerance for higher temperatures rather than the less tolerant pure Arabica species grown in other parts of the world (DaMatta 2004). Unless the hybrid can adjust to higher temperatures coffee production may have to move to higher areas with steeper slopes to maintain production. Opening up new land, particularly steeply sloping land is likely to increase erosion and degrade soils, especially when forests need to be removed or manipulated before planting.

The above analysis does not take into account the impact of extreme or supra-optimal temperatures on crop yields that can potentially have detrimental effects on seed set and seed development. Ben-Asher et al. (2008) evaluated the effect of high temperature on maize and found the highest photosynthetic rate was at temperatures of 25/20 °C

Table 4 The simulated impact of temperature increases on the rate of development and yield of maize in Kenya and peanut in Zimbabwe based on 45 and 50 years, respectively, of daily climatic data (from Cooper et al. 2009)

Climate scenario	Mean seasonal temperature (°C)	Time to maturity (days)	% Reduction from current	Crop yield (t ha^{-1})	% Reduction from current
Maize					
Current	23.3	87	–	3.21	–
Current + 1 °C	24.3	82	5.7	3.08	4.1
Current + 2 °C	25.3	77	11.4	2.92	9.0
Current + 3 °C	26.3	73	16.1	2.76	14.2
					18.8
Current + 4 °C	27.3	70	19.5	2.59	
Current + 5 °C	28.3	67	22.9	2.41	25.1
Peanut					
Current	21.8	119	–	1.43	–
Current + 1 °C	22.8	110	7.5	1.24	13.2
Current + 2 °C	23.8	104	12.6	1.08	24.4
Current + 3 °C	24.8	100	16.0	9.50	33.3
Current + 4 °C	5.82	98	17.6	8.71	38.9
Current + 5 °C	26.8	98	17.6	8.22	42.3

(light/dark) while at 40/35 °C the photosynthetic rate was 50–60 % lower. They also found a gradual decrease in the rate of leaf photosynthesis for each 1 °C increase in temperature. Exposure of maize to temperatures ≥35 °C resulted in drastic yield reductions caused by temperature effects on pollination and kernel set. Exposure to temperatures ≥35 °C has been observed to be lethal to pollen viability in maize (Herrero and Johnson 1980; Schoper et al. 1987; Dupuis and Dumas 1990). A drastic reduction in seed set at high temperatures has also been observed in rice. Jagadish et al. (2007) observed that exposure of rice at peak anthesis to 34 °C for 1 h at about 1100 h caused sterility, while exposure of rice spikelets to >35 °C for 5 days at anthesis induced complete sterility (Satake and Yoshida 1978). In rice, genotypic variation in spikelet sterility at high temperature has been observed in a number of studies (Satake and Yoshida 1978; Matsui et al. 2001; Prasad et al. 2006), attributed to differences in the temperature threshold required to induce sterility (Nakagawa et al. 2002). High temperatures around flowering have been shown to decrease flower number and seed set in peanuts (Prasad et al. 2000, 2001, 2003; Kakani et al. 2002). As the number of days when the temperature exceeds 35 °C is projected to rise near the coast of Timor Leste (Fig. 6a, the potential impact on the yields of crops flowering when temperatures are at a maximum (Fig. 5) is considerable. As maize flowers in January and February when sown in October on the first rains and July and August when sown in April in the southern region of Timor Leste with bimodal rainfall, it is possible for high-temperature-induced sterility in maize sown in October, but unlikely when sown in April on the south coast. However, the greater risk is in rice grown near the south coast which flowers in March and April when maximum temperatures are high and days ≥35 °C are more likely (Figs. 5, 6a).

Warmer temperatures may increase the incidence of insects and fungal diseases that will also decrease yields unless controlled (Patterson et al. 1999), while more frequent droughts have been shown to increase the aflatoxin, a serious carcinogen, contamination in peanut (Battacharjee et al. 2011). On the other hand, an increase in rainfall is likely to increase the incidence of the viral disease groundnut rosette (Battacharjee et al. 2011), and particularly near harvest will slow the speed of drying of the maturing seed, decrease its subsequent germination and potentially increase the level of mycotoxins, such as aflatoxin, in the seed during storage.

Given enough time and assistance in building adaptive capacity to climate change, farmers in Timor should be able to adapt to the relatively small (when compared with current inter-annual variability) increases in rainfall. The predicted increase in temperature for Timor is also comparatively small when compared to the predicted global terrestrial average increase of 3.3 °C by 2050 (Gordon et al. 2002). However, in order to mainstream climate focused evaluation into the 'Seeds of Life' protocol, the selection process must include the known ability of a cultivar to thrive in projected environments. For example, a pigeonpea cultivar imported from abroad should be selected on its ability to produce high yields under today's conditions and to be appropriate for temperatures and droughts likely to be encountered in 2050. As Timor Leste already has spatially variable climates and growing conditions, current selection of new cultivars receive extensive in-country evaluation that are important in preparing agriculture for future climate pressures. Selection and breeding of lines of rice, maize, peanut, cassava and sweet potato adapted/acclimated to higher temperature is likely to be an outcome of the continued breeding and selection activity in cultivar selection programs such as 'Seeds of Life'.

While the adaptation/acclimation to slow, steady increases in temperature and rainfall can be accommodated through breeding and management, the increasing frequency of extreme temperatures are likely to cause greater challenges for farmers. Genetic variation appears to exist in some species for high temperature tolerance. In peanuts it was shown that genotypic variation in the optimum temperature for pollen germination varied from 25.5 to 35.0 °C and for pollen tube growth from 30.5 to 36.8 °C (Kakani et al. 2002) suggesting that selection for high-temperature tolerance is feasible. Based on the observation that the floret is sensitive to high temperature at peak anthesis (Jagadish et al. 2007), the parents used in mapping populations of rice have been screened for their sensitivity to high temperature (Jagadish et al. 2007) for use in breeding of improved heat tolerance in rice. However, considerable further study needs to be conducted to determine the variation in acclimation to high temperatures and high temperature tolerance in crop species.

The speeding up of maturity with the warmer temperatures, coupled with the increase in rainfall, suggests that longer season cultivars may be needed to develop the same leaf area, radiation interception and water use as cultivars in the current climate (Cooper et al. 2009; Vadez et al. 2011; Turner and Meyer 2011). In addition, the longer season cultivars may avoid the necessity of harvesting when there is still a high probability of rain. Increased emphasis may be needed in improving the insect and disease resistance of these crop cultivars to cope with the increased insect and disease pressure induced by climate change.

One of the consequences of climate change is that crops may need to be grown in different areas than at present. Maize should be able to be grown at higher elevations in Timor Leste. As rice is grown in bunded and levelled fields, the potential to grow rice at higher elevations will be more difficult. Nevertheless, with the potential of increased sterility and crop failure at the warmer sites on the south coast, greater emphasis on development of suitable sites at higher elevation may be necessary, particularly if cultivars with greater heat tolerance cannot be sourced.

High elevation, temperate crops may be the most affected of all the crops. While this region (above 2000 m) is small (<2 % of the total land area), the production of temperate crops (wheat, barley, potato, carrots and cabbage), fruits and cattle could be strategic for the country in future. If increases in temperature push crops above their tolerance levels, with no higher elevations to move to, they will have to be replaced with more temperature hardy, tropical species.

Cassava is well adapted to hot tropical climate with optimum growth reportedly occurring at 25–29 °C and requiring a high temperature (35 °C) and high solar radiation (1800 μmol $m^{-2} s^{-1}$) for optimal leaf development and maximal photosynthesis (Alves 2002). Storage root yield and total biomass are positively correlated with the rate of leaf photosynthesis (Alves 2002). Cassava is also drought tolerant (Alves 2002). Thus, production of cassava may replace maize on the hotter and drier north coast and in the longer term replace rice on the south coast if rice fails to thrive. However, a recent report indicated that the increase in CO_2 may reverse these benefits in hotter and drier environments. A doubling the level of CO_2 in the atmosphere drastically reduced the total biomass and halved the number and size of tubers, leading to an 80 % reduction in harvest index (Gleadow et al. 2009). The high CO_2 doubled the deadly cyanogenic glycoside concentrations in the leaves, but not in the tubers. Cassava leaves are widely consumed as an accompaniment to starchy foods (cassava tubers, maize and rice), giving the meal an important protein, iron and vitamin boost. As protein deficiency is the major contributor to malnutrition in Timor Leste and meals with a high cassava tuber content are particularly prone to low protein contents, substituting leaves for tubers is a very effective way of increasing protein intake in subsistence households (Wargiono et al. 2002). While there is no empirical data on cassava leaf consumption for Timor Leste, in neighbouring Indonesia cassava leaf production is estimated at 0.5–0.7 million t $year^{-1}$ (Wargiono et al. 2002). As cyanogenic glycoside breaks down to produce toxic hydrogen cyanide care will be needed in using the leaves of cassava to avoid increased deaths in future.

IMPACT OF POPULATION GROWTH ON CROPPING SYSTEMS

While climate change will impact on the cropping systems of Timor Leste in the long term, the rapid increase in the population is likely to have a bigger impact than climate change in the short-to-medium term. The projected increase of the population to 2.5–3 million by 2050 (Fig. 2) and the failure of agriculture to provide food security and sufficient calories and protein in 2010 suggests that radical improvements will be required if the population is to be adequately fed and malnutrition overcome. In all regions of the world where population has increased so that land becomes a greater constraint than labour, shifting agriculture has been abandoned in favour of settled agriculture (Allan 1965). In order to make this shift in Timor Leste, a number of new technologies will be required.

To sufficiently increase yields of all the food crops in Timor Leste, fertilizer use, almost non-existent at present, will need to increase. While the use of high-yielding cultivars has improved crop yields as outlined above and in Tables 2 and 3, studies have shown that even greater yield increases are possible with the responsible use of minimal amounts of fertilizer. In a replicated study with four high-yielding lines of maize and one local check conducted at two sites in Timor Leste, Seeds of Life (2007) showed that 15 kg N ha^{-1} and 15 kg P ha^{-1} increased yields by 44 % (range 13–84 %) on average over the unfertilized plots. Application of 15 kg ha^{-1} of nitrogen, 15 kg ha^{-1} of phosphorus and 15 kg ha^{-1} of potassium to local and introduced cultivars of maize showed that the high-yielding introduced cultivar responded more to the fertilizer than the local cultivar with the yield of maize increasing from 2.8 to 5.2 t ha^{-1} with the introduced cultivar (SW5 from CIMMYT) compared to 1.7–1.9 t ha^{-1} with the local cultivar (Arjuna) (ACIAR 2004). Application of 15 kg $ha^{-1}$of phosphorus and 15 kg $ha^{-1}$of potassium to peanut at 24 sites increased yields from 2.9 to 3.8 kg ha^{-1}. A cost-benefit analysis indicated that the benefit:cost ratio for fertilizer application was 4 for maize and 5.5 for peanut (Williams and Ximines, unpublished), suggesting that use of fertilizer was highly profitable and that surplus grain could provide a cash income for farmers. Methods for judicious use of inorganic fertilizer can be developed that not only include limited application amounts, but that also improve application techniques and nutrient use efficiency. These include the deep placement of urea in paddy fields or fertilizer microdosing for maize, both of which drastically reduce the expense and waste associated with broadcast fertilizer application and increase yields in a more affordable manner appropriate for low yielding, low income smallholder farmers (Bowen et al. 2005; Sawadogo-Kaboré et al. 2009; Singh et al. 2010).

The World Bank (2007) identified the lack of fertilizer and other technological innovations as the reason for the lack of poverty reduction in Sub-Saharan Africa, while Lefroy (2008) showed that the change in net production between 1965 and 1995 among different regions was linearly related to their change in fertilizer use over the same period. While China had a very high change in production associated with a high fertilizer increase of nearly 250 kg NPK ha^{-1}, Oceania (including Timor Leste) had little change in net production between 1965 and 1995 which was associated with <5 kg NPK ha^{-1} increase in fertilizer application (Lefroy 2008).

Increased crop productivity as a result of improved cultivars and species, will be of little benefit if farm losses are not reduced. Thus, facilities for on-farm storage by smallholder farmers need to be explored. This will not only allow farmers to preserve cereals for the ‘hungry season’ after planting, but will also enable farmers to conserve cereals from a year with high production (with timely rains and moderate temperatures, for example) for a year with low production (with low wet-season rainfall or high temperatures, for example).

In addition to the use of inorganic fertilizers, increasing soil organic matter by the incorporation of crop residues and animal manures will benefit soil structure and increase yields. Conservation farming that incorporates basins to minimize runoff and greater water infiltration, mulching to reduce water loss by soil evaporation, timely planting on the first rains, application of manure to provide better soil structure, top dressing with fertilizer depending on rainfall, rotation with legumes, and timely weed control, have been shown to increase yields by up to 100 % over conventional farming and increase profitability in southern Africa (Mazvimavi et al. 2008). The use of velvetbean *Mucuna pruriens* as a green manure crop is an indigenous technology in Timor that has been used to ensure sustainable maize production in Honduras (Buckles et al. 1998). Successful trials of velvetbean as a green manure/cover crop with maize have been undertaken by Seeds of Life (Seeds of Life 2007). As an additional benefit, these trials could be expanded to identify other *Mucuna* species and legume alternatives which are more appropriate for human consumption. Exploring opportunities for using velvetbean biomass as a forage and fodder crop for livestock should also be considered.

Some of these conservation farming practises will also benefit the soil stabilisation on slopes. Much of Timorese land is sloping, with only the slim coastal area of the north coast, some high elevation plateaus (such as around Gariuai in Baucau and the lake Iralalaru plain in Los Palos) and the frequently inaccessible south coast low-lands offer shallow gradients conducive to agriculture. Much of the sloping, more marginal lands are subjected to slash-and-burn subsistence agriculture, which if done infrequently by few enough farmers and given enough time to fallow/regrow can maintain sustainable production (Russell 1988). However, as population densities increase from 72 to 200 km^{-2}, the per capita area available for agricultural cultivation will be reduced. Under this scenario, slash-and-burn fallow periods are likely to shorten (Turner et al. 1977), or more marginal less productive land will be used to accommodate more users, hence lowering yields, as nutrient recovery diminishes and forest (which no longer has enough time to recolonise fallow lands) is replaced by grasses (Russell 1988). When the factor of climate change is included, particularly increased temperatures which will likely push crop ranges to higher elevations, the areas of land appropriate and available for slash-and-burn farming will decrease as land areas reduce and gradients increase with elevation.

Conservation farming, in a settled agricultural system, can improve the land to productivity ratio and hence accommodate a higher population from a smaller land area, without requiring fallow periods or having to encroach on marginal or forest lands. Done well, conservation farming can also increase productivity through improving labour efficiency over shifting slash-and-burn systems.

The requirement of large areas of land (the vast majority of which must remain fallow for most of the time) also undermines the potential of shifting agriculture to compete with intensive farming under the high population pressures (Boserup 1965) and the increasing urbanisation taking place across most of the world, including Timor Leste (FAOSTAT 2010; National Statistics Directorate 2010). Increasing populations reliant on a fixed area of land for food production require more food from that land than before, therefore requiring an increase in production per hectare or expansion into previously unused marginal lands. Rural-to-urban migration can create an imbalance of demand and production of food, reducing the availability of rural labour (farming is labour-constrained in Timor Leste’s subsistence agriculture) and increasing the demand for food in the cities. Increasing urban populations are net consumers of food (with the notable exceptions of peri-urban food production and home gardens) and require the remaining, rural population to provide the market with food crops (Hunt 2000), unless imports are expected and accepted to cover the food requirement deficits.

Increasing the productivity of slash-and-burn agriculture is, however, limited by its shifting nature and reliance on manual labour; investment in site-specific, labour-intensive/costly improvements such as irrigation and tree root clearing for ploughing are not viable, and any increase in labour input in order to increase output in a subsistence system comes with a diminishing return on productivity (Boserup 1965). Without the adoption of technology through investments and improvements (that require continuous use of one area), shifting cultivation must rely heavily on rainfall, hand planting and weeding, all of which present serious limitations to increased productivity and heighten its susceptibility to problems from climate variation, particularly variation in rainfall. Some intensification through settled agriculture can therefore be seen as helpful for feeding a growing population in a fixed area and a rural-to-urban migrating population where a large proportion of the population no longer engages in the farming production. Settled agriculture can also help to reduce the impacts of climate variability through allowing irrigation investments.

Where settled agriculture is adopted the seasonal and usually tilled nature of the new farming system on Timor Leste's steeply sloping areas will increase the risk of soil erosion on the thin, friable soils, especially if all weeds are removed and bare soil exposed at the beginning of the wet season. Conservation farming interventions will be required to prevent severe erosion, loss of topsoil and any fertilizer and manures applied. Terracing of slopes has been widely adopted on the Loess Plateau of China where the loess (silt) soils are particularly vulnerable to water erosion (Cao et al. 2007; Gao and Deng 2007). Shepherd (2009) reported on the development of terraces in several communities in Timor Leste, encouraged by the USC-Canada, Timor Leste, a Non Government Organisation. The 1.5-m-wide terraces, stabilized with leguminous trees and other food crops, improve water infiltration and water quality, and reduce soil erosion and deforestation, particularly on overgrazed eroded hillsides (Mateus Soares Maia, pers. comm.). With training, but no financial support, terracing for food and fodder production has been adopted by over 100 farmers in Timor Leste (Mateus Soares Maia, personal communication, November 2010). Alternatively, micro-catchments can be dug in the dry season to capture rainfall for each hill of maize or cassava as proposed for maize production in Africa (Mazvimavi et al. 2008). On the slopes, these would need to be half-moon shaped so that the water does not flow over land but is captured in the hollow surrounding each plant. An alternative that has been adopted in parts of south-east Asia is the use of contour hedgerows using either trees or other vegetation to stabilize crop production on slopes (Garrity 1996; Doanh and Tiem 2003).

Hedgerows of shrubs that can be used to increase soil fertility such as *Gliricidia sepium* or *Leucaena leucocephela*, or hedgerows of grasses such as *Pennesetum purpureum* Napier grass *or Paspalum conjugatum* are used to prevent water and soil movement down the slope. The soil from the upslope position is gradually washed to the stems of the downslope hedgerow so that gradually over time mini-terraces are formed between the contour hedgerows (Garrity 1996). The hedgerows can be pruned or cut to provide fodder for animals, wood-fuel for cooking, or left on the ground and/or burned to provide nutrients for the subsequent crop. Doanh and Tiem (2003) suggest a mixture of interventions to reduce erosion and leaching and improve crop production on slopes. They suggest intensive cultivation of land in the valleys, use of semi-perennial crops such as sugarcane that can be ratooned for several years or high-value, quick-growing forest trees such as bamboo on the slopes and contour hedgerows for hedgerow cropping. While these crops may not be appropriate for Timor Leste, use of Napier grass on terraces is being adopted for feeding of penned animals to reduce free grazing and subsequent overgrazing and soil erosion of hilly slopes in Timor Leste. As some of these interventions have not been trialled or have had only limited trialling in Timor Leste, their compatibility with the working calendar of farmers needs to be investigated.

To overcome malnutrition, particularly protein deficiency, improvements in livestock production, particularly small animals such as pigs, sheep, goats and chickens will be required. The use of contour hedgerows with grasses and leguminous shrubs that do not compete with food crops could provide improved fodder for penned animals or for grazing in the dry season. Studies have shown that penning pigs and providing crop residues such as rice bran, or leaves of leguminous trees, such as *Gliricidia* and *Leucaena* can lead to improved meat production (Soares 2009). In addition, the introduction of a range of legumes is suggested. Small areas of peanut are already grown and some beans such as kidney beans and soybean are grown in association with maize, but there are likely to be a range of crop legumes that need to be trialled to obtain higher yielding cultivars as has been done for maize, rice, cassava, sweet potato and peanut. Suggested legumes that should be pursued further are cowpea, winged bean and pigeon pea.

CONCLUSION

While increases in temperature and rainfall in Timor Leste as a result of climate change over the next 40 years are considered to be modest (an increase of 1.5 °C in temperature and 10 % in rainfall), the almost tripling of the population is likely to provide a challenge to maintaining food security. The traditional shifting slash-and-burn agriculture is unlikely to be sustainable as population pressures increase and interventions will be required to ensure an adequate supply of calories and protein without resorting to food imports. The selection of higher yielding cultivars of staple crops will need to continue and new crops, particularly food legumes, and improved animal production systems will be required to provide sufficient protein. The judicious use of fertilizers have been shown to considerably improve yields and terracing or the use of contour plantings of perennial trees or grasses will be necessary to stabilize slopes and maintain agricultural production as farmers move towards settled agriculture from shifting agricultural systems. Research to test and evaluate new cultivars, new species and suggested interventions will be an ongoing requirement.

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