

Review Article

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Roots, Tubers and Bananas: Planning and research for climate resilience

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Abstract: The CGIAR Research Program (CRP) on Roots, Tubers and Bananas (RTB) includes vegetatively propagated staple crops linked by common breeding, seed, and postharvest issues, and by the frequency with which women are involved in their production and use. RTB crops are the backbone of food security across the humid tropics in sub-Saharan Africa (SSA) and in more localized areas of Asia and Latin America. Around 300 million poor people in developing countries currently depend on RTB value chains for food security, nutrition and income. Climate change poses challenges which could undo progress in poverty reduction and markedly increase food insecurity. This article examines planning and research for climate resilience across RTB crops, with a particular focus on the contrasting potato and sweet potato cases in SSA. A six-step framework for climate-smart breeding is proposed: (1) downscaling climate change models and crop modeling; (2) identifying and understanding key climate change responsive traits; (3)

breeding and varietal selection; (4) phenotyping and genomic research to accelerate gains; (5) developing management options for climate-smart varieties; and (6) deployment (seed systems). In summary, climate-smart breeding means we need to do what we already do but faster, better, and smarter.

Keywords: roots; tubers; bananas; potatoes; sweet potato; climate change; poverty; breeding

1 Introduction

The CGIAR Research Program (CRP) on Roots, Tubers and Bananas (RTB) is one of eight Agri-Food System CRPs (AFS-CRP). It incorporates livelihood systems work, especially with strong collaboration from the CRP Integrated Systems for the Humid Tropics (Humidtropics), and expands collaboration with Global Integrating CRPs (GI-CRP) and the other AFS-CRPs making up the portfolio. RTB is led by CIP, with Bioversity International, CIAT, IITA, and CIRAD as managing partners, and over 350 research and development partners. RTB brings together research on its mandate crops: bananas and plantains, cassava, potato, sweet potato, yams, and minor roots and tubers. Termed “vegetatively propagated staple crops,” they are linked by common breeding, seed, and postharvest issues, and by the frequency with which women are involved in their production and use. RTB crops are the backbone of food security in humid tropical countries of sub-Saharan Africa (SSA) and in areas of Asia and Latin America. Elsewhere, RTB crops often complement maize, rice, wheat, legumes, vegetables, and livestock, while also forming part of many agro-forestry systems. Around 300 million poor people¹ in developing countries

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¹ Based on expert estimation with poverty line defined as earning less than US \$1.25 at 2005 purchasing power parity (World Bank 2015).

currently depend on RTB value chains for food security, nutrition, and income; many more benefit through their consumption. RTB crops are increasingly taking on roles in income generation. However, climate change could potentially undo progress in poverty reduction and markedly increase food insecurity, especially in SSA where RTB crops are very important.

This article examines planning and research for RTB crop climate resilience with a particular focus on potato and sweet potato in Africa. These contrast in the agro-ecological niches they occupy and their roles in livelihoods. Potato is found at higher, more temperate elevations and is a more input-intensive cash crop. Sweet potato grows at lower, more tropical elevations and is a more robust crop for food security. Both are expanding very rapidly in Africa and are likely to be impacted differently by climate change. This article proposes a general framework for climate-smart breeding to address these challenges.

2 Climate change and poverty impacts

Through the humid African tropics RTB crops are the most important staple and the dominant commodity in the system. The contribution of foods derived from RTB crops to total caloric needs ranges from nearly 25% in Nigeria to close to 60% in the Democratic Republic of Congo (RTB 2016).

There are marked cultural preferences for RTB crops in these SSA countries. Using the Impact General Equilibrium Model, a 2015 analysis in by the International Food Policy Research Institute shows that per capita consumption will continue to rise (Figure 1). Because of low productivity, current RTB production in SSA does not meet basic needs in rural areas. Moreover, low productivity often weakens the crops' competitiveness with imported staples for urban consumers, resulting in missed smallholder income



WLD = World; EAP = East Asia and Pacific; EUR = Europe; FSU = Former Soviet Union; LAC = Latin America and Caribbean; MEN = Middle East and North Africa; NAM = North America; SAS = South Asia; SSA = sub-Saharan Africa. Bananas are included under fruits and vegetables.

Figure 1: Forecast sustained per capita demand for roots and tubers to 2050 (source: K. Wiebe 2015)

opportunities. As more people move to cities, value chains for RTB crops will need to be reconfigured to improve efficiency and convenience and reduce postharvest losses to compete.

Climate change will impact agri-food systems and worsen poverty in different ways. One of the most important effects is through reducing productivity and raising food prices (Figure 2). This is of concern worldwide, but without significant technology to cope with climate change this is likely to be of special importance in SSA. This is precisely where RTB crops are of the highest relative importance, with further expansion in the pipeline as the population of these countries continues to grow. Technological change in roots and tubers is essential to damp food price increases and risk of hunger under any climate change scenario. This article focuses on climate-smart breeding as a key element in the RTB response.

2.1 Steps in climate-smart breeding

RTB has identified six steps in climate-smart breeding. These are not sequential as some steps feed back to earlier ones. They are:

2.1.1 Step 1. Looking into the future

Downscale climate change models and crop modeling to (a) define target environment sets by crop, and (b) understand yield impacts and drivers of yield loss by crop (including pests). Climate change impacts crop yields in complex ways as depicted in Figure 3. Increasing carbon dioxide (CO₂) concentrations can have a fertilization effect and some locations will show higher rainfall, but increased heat or drought can adversely impact yield.

Jarvis et al. (2012) used different global climate change models linked with the Ecomodel of crop suitability and parameters of major staples in SSA. Potato was one of the crops that showed the greatest negative effects - crop suitability declined ($-14.7\% \pm 8.2$) by 2030, along with beans ($-16\% \pm 8.8$), probably because they occupy similar highland climatic niches. Cassava was positively impacted by climate change in many areas of Africa, with -3.7% to $+17.5\%$ changes in climate suitability across the continent. The results, however, are difficult to relate directly to yields, as they would be sensitive to the parameter values selected, such as maximum temperatures tolerated. Furthermore, sweet potato was not included in the exercise. As the authors also recognize, indirect effects of climate change on cassava through buildup of pests

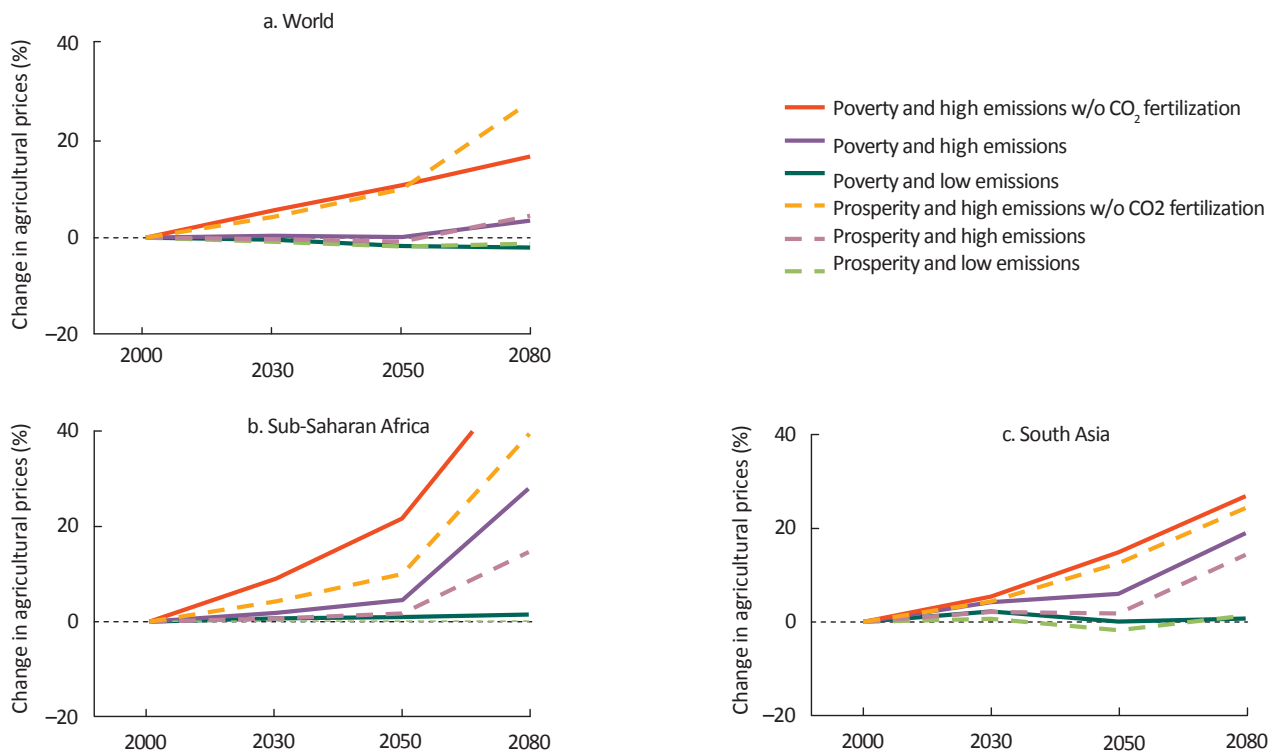
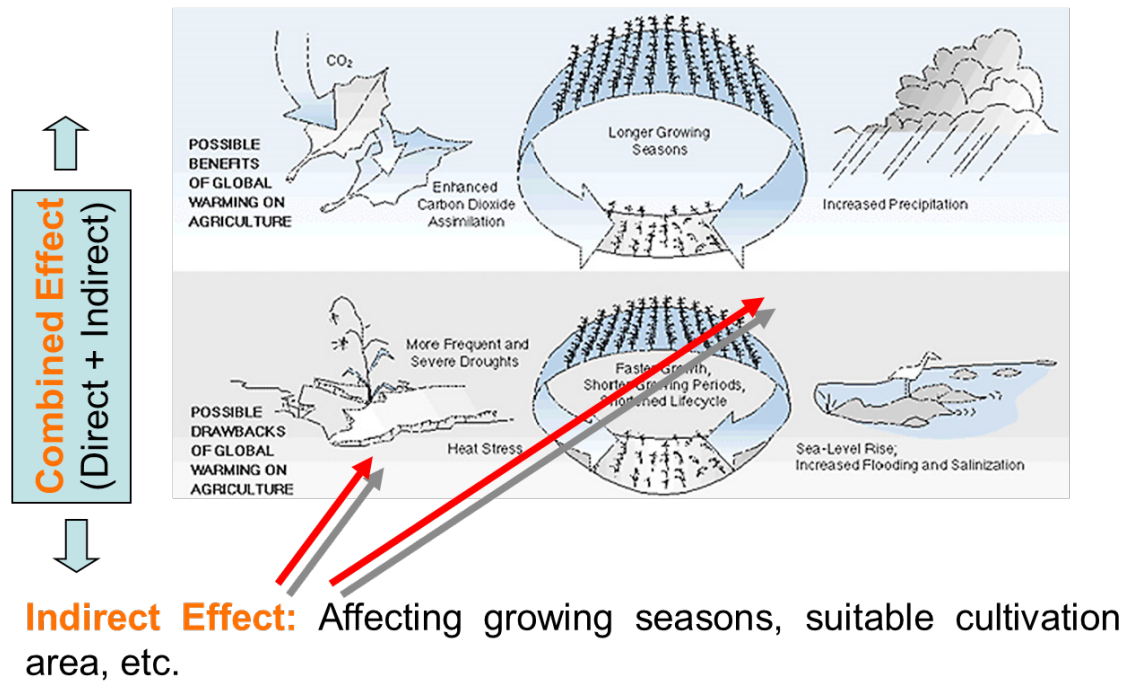


Figure 2: Effect of climate change on agricultural prices under different scenarios (source: Hallegatte et al. 2016)

Direct Effect: Stimulating radiation and water use efficiency



Bindi 2008

Figure 3: Effects of climate change on crops (source: M. Bindi, University of Florence, 2008)

and diseases could be significant, which would require additional modeling.

The models need to be adjusted to different genotypes that have been bred for higher temperature tolerance and adaptation to tropical regions.

Washington et al. (2012) similarly used an ensemble of general circulation models to predict spatial changes in the distributions of 10 crops in East Africa. In general, they found that crop distributions may be more affected by temperature changes than by rainfall changes, favoring crops with higher temperature thresholds (e.g., banana, cassava, and pigeon pea). From their analysis, no areas of East Africa are currently optimal for potato production; with increasing temperatures projected over the 21st century opportunities for cultivation are likely to diminish. However, differences in potato genotypes for higher temperature tolerance could affect the projections. For sweet potato, although the extent where the crop can be grown is unchanged, the suitability is so reduced that no optimal areas remain by the end of the century. Figure 4 is a representative suite of models. This finding contrasts with that for cassava, which showed some increase in suitability in area to 2050.

In addition to the direct effects of climate there are complex indirect effects via pests and diseases. Sparks et

al. (2014) used a metamodel based on Simcast, which uses the relationship with temperature and relative humidity to predict changes in the severity of potato late blight (LB), the most severe fungal disease affecting potato worldwide. Ethiopia and the Lake Kivu area could have a marked increase in LB severity by 2050. The projected increase in these areas from around 1 daily blight unit to 4 units would mean an approximate increase in spraying from once a month to weekly in a susceptible variety (Figure 5).

An alternative approach is to look at the current complex of pests and diseases across an altitude profile (Figure 6). The lower altitude is an analogue for the future climate of the adjacent higher area. The gradient allows us to study crops and pests under different environments. RTB has supported pest risk assessment exploiting this principle in East Africa. To create temperature surfaces and simulate and map climate impacts on pests, 52 weather stations were equally distributed to record current climate conditions at two action sites along a gradient from 810 to 2,520 masl. The framework for studying the impacts of climate change is based on regional climatic data, pest models to predict and estimate potential changes in pest range and abundance, and pest-induced losses of RTB crops. Farm household models will be developed to understand impacts on farmers' livelihoods.

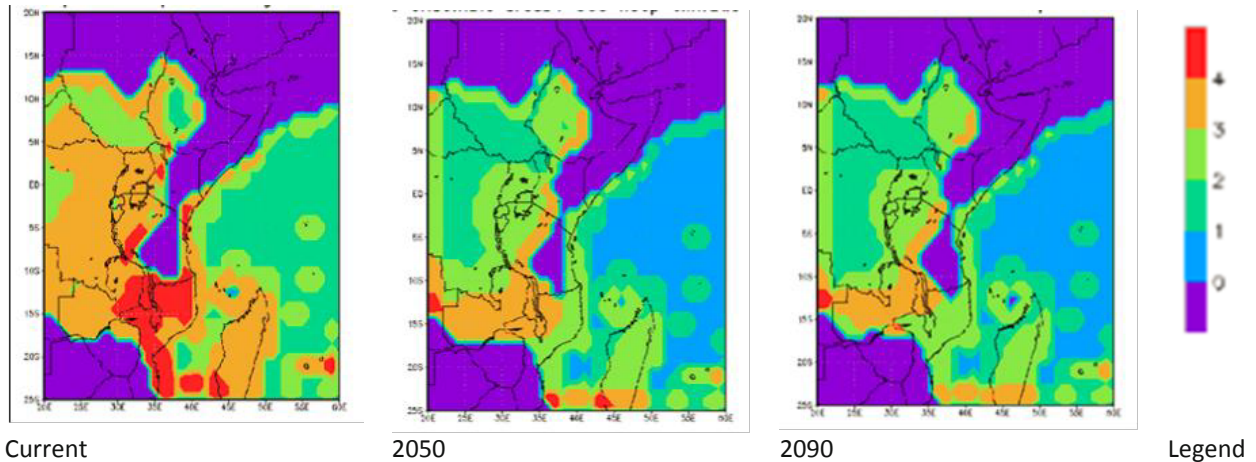


Figure 4: Suitability of sweet potato cultivation in East Africa under high emissions scenario (source: Washington et al. 2012. Ensemble sresb1 JAPRE Climatic Growth Area). Scale: 0 = not adapted, 4 = optimally adapted

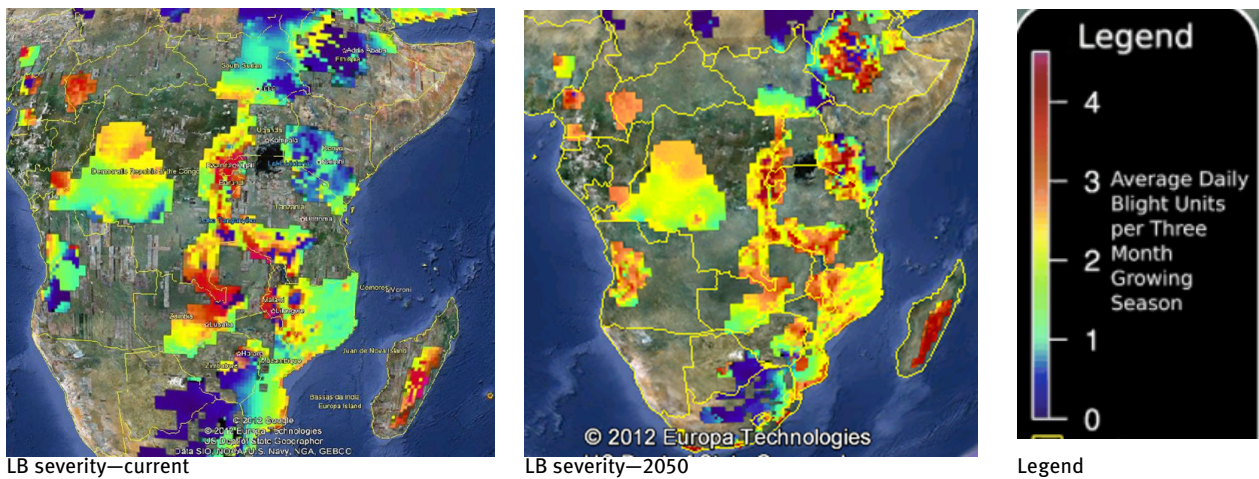


Figure 5: Predictions of potato late blight severity in sub-Saharan Africa using a metamodel (source: Sparks et al. 2014)

Substantial effects on suitability and pest increases can be anticipated. Studies (e.g., in the Kabale District of Uganda) revealed that sweet potato weevils (*Cylas* spp.) occurred up to an altitude of >2,400 masl, but infestation rates were significantly higher (77%) at low altitudes (1,422–1,814 masl) and lower (23%) at altitudes of 1,992–2,438 masl (Okonya and Kroschel 2013).

Range expansion of *Cylas puncticollis* to higher altitudes and to Southern Africa under a changing climate is projected using advanced pest models and GIS pest risk mapping (Figure 7) (Okonya et al. 2016). The risk maps also clearly indicate that in many regions the pest will develop two additional generations per year, increasing its abundance causing higher infestations and losses.

Further work is needed to verify the model parameters. This includes using currently available germplasm that is better adapted to the tropics to understand how this

impacts actual yield losses, and identify the constraints to target through breeding.

Research into climate suitability, pest resistance, and diseases has been going on for a long time (Khan et al. 2016), but breeding traits may need to be reprioritized. The rapid changes in climate make this even more urgent.

2.1.2 Step 2. Identifying and understanding key climate change responsive traits

Development stages where potato and sweet potato are most susceptible to climate change stresses should be identified. This is followed by identifying key traits, estimating trait levels needed, developing novel phenotyping approaches, and determining trait components, interactions, and trade-offs (i.e., collateral

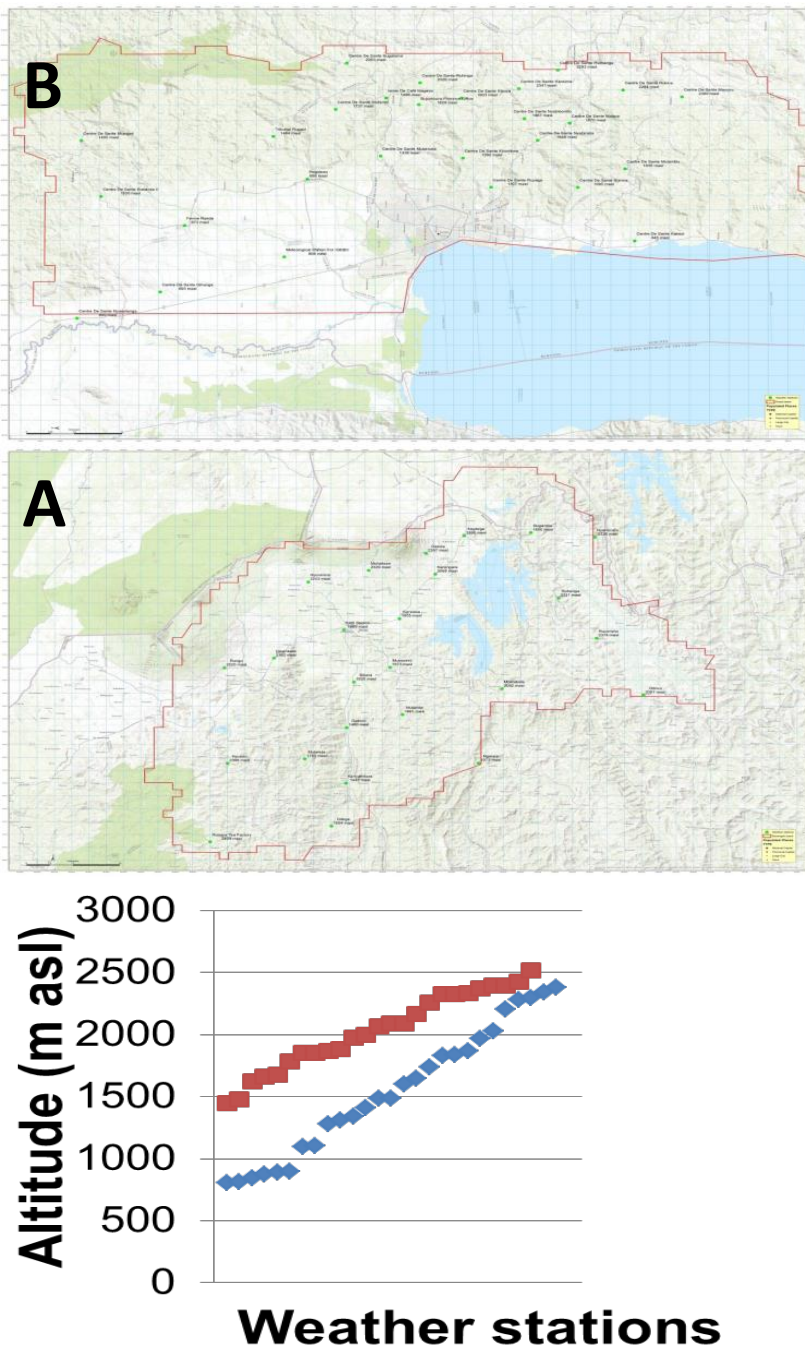


Figure 6: Altitude and location of weather stations: A) Rwanda: Ruhengeri - red points: 1,400-2,500 masl B) Burundi: Rusizi valley - blue points: 800-2,500 masl

effects on quality). Maintaining yields may require enhanced heat and drought tolerance, which are controlled by different physiological mechanisms and genetic pathways.

High temperatures affect many processes in the plant. In addition to photosynthetic rate and metabolism related to dry matter (DM) accumulation, tuber initiation and development in potato are negatively affected by high temperatures (Kooman and Haverkort 1995). Gajanayake et al. (2015)

report that high temperatures have detrimental effects on all stages of sweet potato storage root development. At night, temperatures greater than 17°C significantly reduced yield and a day/night 40°C/32°C, reduced yield by 94%, compared with 25°C /17°C. These processes are mediated by the interaction of phytohormones such as auxins, cytokinins, jasmonic acids, and abscisic acid, and coordinated expression of several genes influenced by environmental and edaphic factors (Ravi et al. 2009).

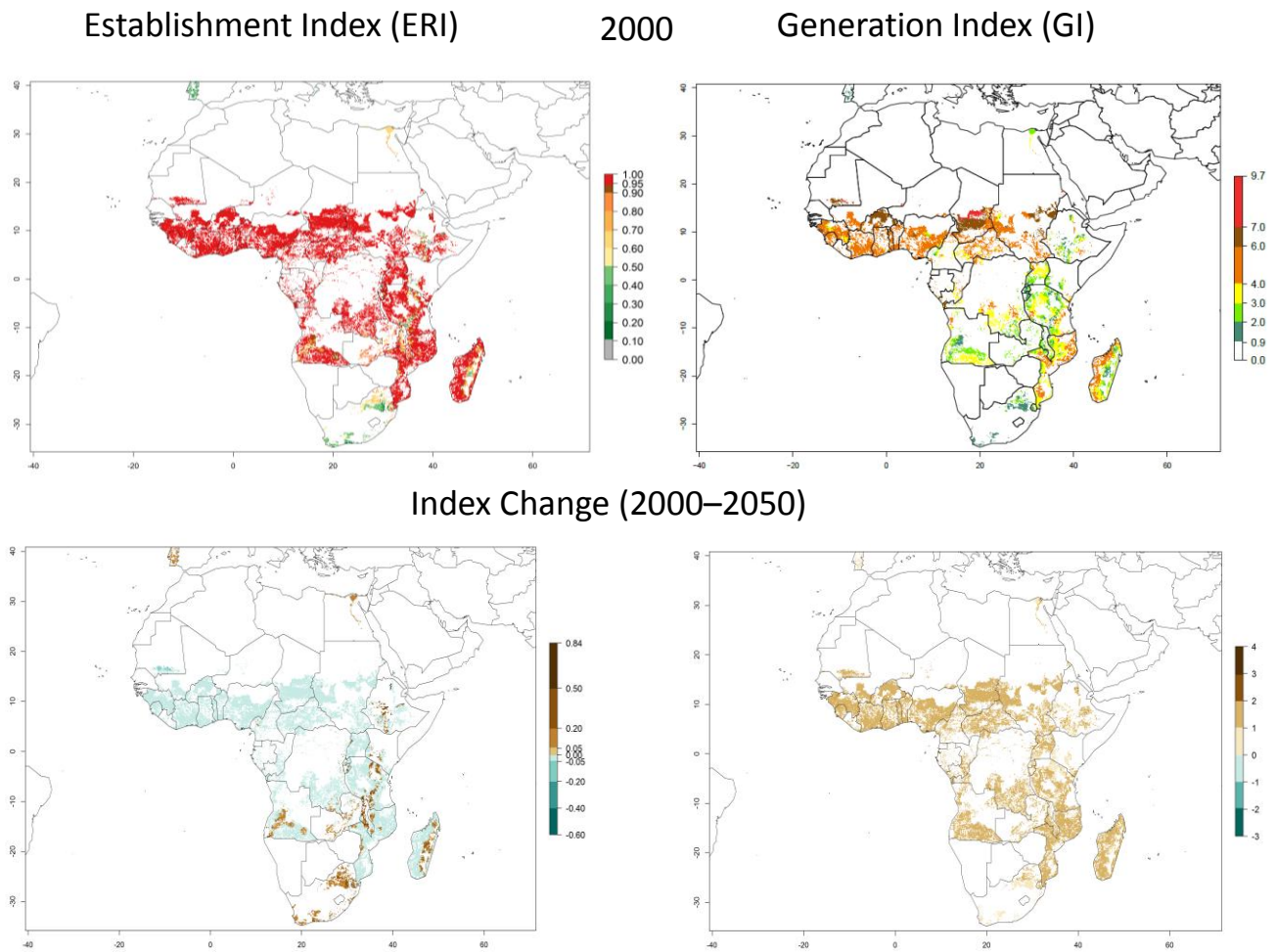


Figure 7: Changes in establishment and potential distribution (ERI) and abundance (GI) of the sweet potato weevil, *Cylas puncticollis*, in sweet potato production areas of Africa according to model predictions, using the ERI and GI for the years 2000 and changes of the ERI and GI between 2000 and 2050 (Index Change). An ERI>0.95 is associated with potential permanent establishment of the pest (source: Okonya et al. 2016)

CIP has ongoing research on the effects of drought and other stresses on potatoes in Peru using movable plastic shelters to simulate drought (Figure 8).

A series of component traits can be identified that contribute to drought tolerance, including canopy temperature during periods of stress (Table 1).

It is widely accepted that root architecture plays a role in drought adaptation (Khan et al. 2016); however, root architecture is poorly understood and little is known of its role. Ongoing studies at CIP and elsewhere are developing protocols to study this trait, which is complex, difficult and expensive to assay (Comas et al. 2013). The trait includes the following root architecture parameters:

- axes
- angles
- branching
- length

- volume/density
- number

All of these may influence the ability of crops to take up water and nutrients from different soil profiles and hence their capacity to tolerate heat and drought. Research is underway at CIP to understand this for the potato by growing plants in open trays. Progress is being made to identify the loci controlling the number of days to root initiation (A. Khan, pers. comm.).

In addition to the adverse effects on yield, there may also be effects on quality. This has a direct bearing on potato breeding. A CIP meta-analysis from the evaluation of a lowland tropics virus resistant population (LTVR) of 300 advanced lines grown in 3 replicates, across environments in Peru suggests that as temperature increases DM declines (Figure 9). However, selection



Figure 8: CIP Potato research plots in Peru (source: A. Khan, pers. comm.)

Table 1: Component traits for drought tolerance (source: A. Khan, pers. comm.)

Component traits	Variable
Root traits	Root length Number of roots Root fresh and dry weight Root angle
Stolon traits	Stolon number Stolon diameter Stolon fresh and dry weight
Tuber traits	Tuber number Tuber fresh and dry weight
Harvest Index	Tuber fresh weight (FW)/Total biomass (FW)* X 100 *Total biomass= FW (leaf + stem + stolon + tuber +root)
Physiological traits	Chlorophyll content (SPAD) Canopy temperature Canopy reflectance (NDVI)
Biochemical	Metabolite profiling and NIRS

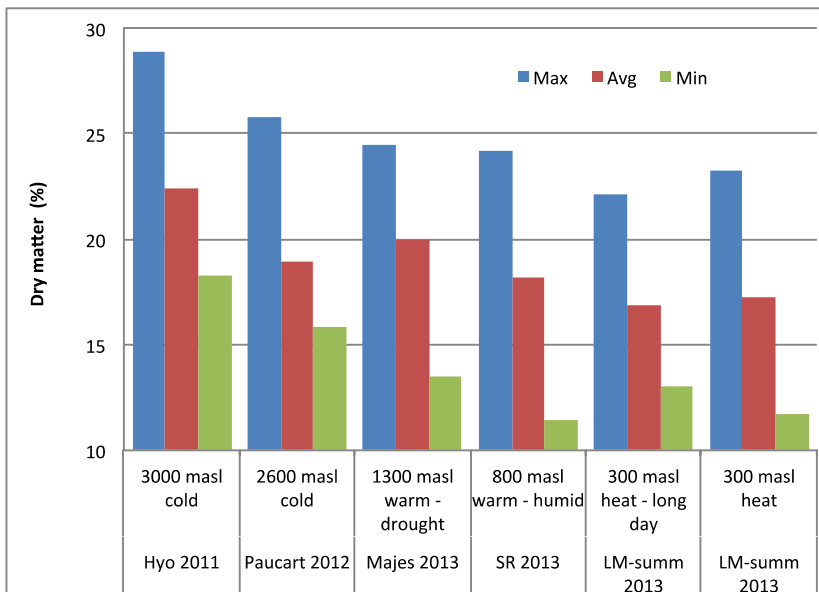


Figure 9: Effects of six temperature regimes on dry matter production of advanced lines of a potato LTVR population grown at five different altitudes in Peru (source: Bonierbale & Amoros 2016)

for DM ensures that DM is satisfactory even under the warmest conditions. This shows the importance of maintaining diversity in the population and of multi-trait selection procedures that monitor quality traits as well as yield.

Glycoalkaloid accumulation in tubers due to heat can lead to a bitter taste and food safety issues (M. Gastelo, pers. comm.). Consequently, in breeding for climate-smart crops quality components must be screened, and phenotyping protocols and molecular tools must be developed and used for these.

2.1.3 Step 3. Breeding and varietal selection

There are a number of challenges for breeding and varietal in selection for climate resilience:

- Combining multiple traits
- Drought and heat are seldom the sole stress factors
- Stresses are not yearly events
- Plants' different physiological mechanisms
- High importance in RTB crops of variable market and consumption preferences.

Key targets for potato breeding have recently been identified (RTB 2016). Climate change does not throw up new traits, but rather shifts the level of the trait needed and creates an additional challenge, as the trait variance is likely to increase along with the mean. Table 2 displays an example for potato.

Potato production in the subtropical lowlands of Southwest Asia is a good example of the challenges. Here the cool temperature window is limited and is becoming even shorter with rising temperatures. Breeding for early maturity and heat tolerance is paramount. Both yield and quality need to be maintained under high temperatures at planting time and during the bulking period. It will be necessary to maintain DM, yield, and freedom from heat defects in less time.

Using novel selection tools in early generations, parent lines are being selected to maximize genetic gains. These tools include proximal sensing for canopy temperature and Normalized Difference Vegetation Index (NDVI). They can be used to identify superior cross combinations for distribution to target environments where early maturing heat-tolerant varieties are sought.

Selection results in superior progeny performance. A trial was carried out in San Ramon, Peru under climatic conditions similar to those prevalent in SSA (30°C day/22°C night; in a randomized complete block design, where clones were grown in 3 replicates in blocks of 10 plants each; yields are means of the three replicates, with individual clones shown as yellow triangles). Figure 10 shows that selections performed significantly better than past generations and local varieties for yield and quality across environments at 70 days after planting. The target is 70-80 day heat-tolerant potatoes for Southwest Asian subtropical lowlands.

2.1.4 Step 4. Applying phenotyping and genomic approaches

RTB supports genomic research to identify traits for heat tolerance. Screening of 1,973 sweet potato accessions from the CIP genebank was carried out at two environments in north Peru:

- Heat stress (summer): mean soil temperature at night: 30°C
- No heat stress (winter): mean soil temperature at night: 24°C.

The lines were grown in an α -lattice design, with two replicates for each environment. The prioritized traits were heat tolerance and early bulking. Plant performance and yield-related traits were also assessed. The trial used remote sensing as a fast method to screen the effects of heat (Figure 11).

Table 2: Target traits for potato (source: RTB 2016)

Region	Target traits	Target level 2022
African and Andean highland tropics	Drought tolerance	90–110 days to maturity
	LB resistance	Drought tolerance in 20% of clones
	biofortification with Fe and Zn	LB susceptibility score of 2-3
	Table-potato preference	45 ppm of Fe and 35 ppm of Zn 130 mg vitamin C /100g FW
African and Asian mid-elevation tropics	Resistance to LB and potato virus Y (PVY)	90 days to maturity
	Chipping ability	PVY extreme resistance, resistance to potato leafroll virus
	Heat tolerance	LB susceptibility score of 3-4
	Low anti-nutrient content	tuberization and bulking under warm day temperatures 80% of clones show no glycoalkaloid formation under stress

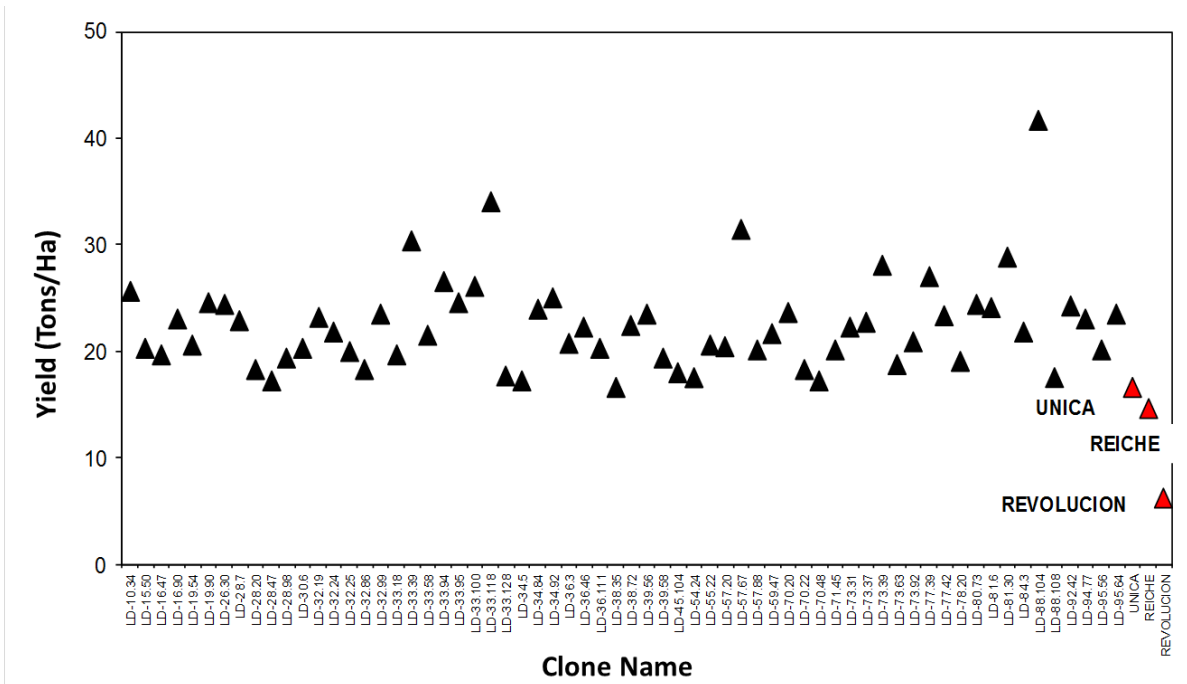


Figure 10: Fresh yield (t/ha) at 70 days after planting new clones (black triangles) of a virus resistant potato population growing in the lowland tropics, and three local varieties (Unica, Reiche, and Revolucion; red triangles with black outlines) (source: M. Bonierbale, pers. comm.)

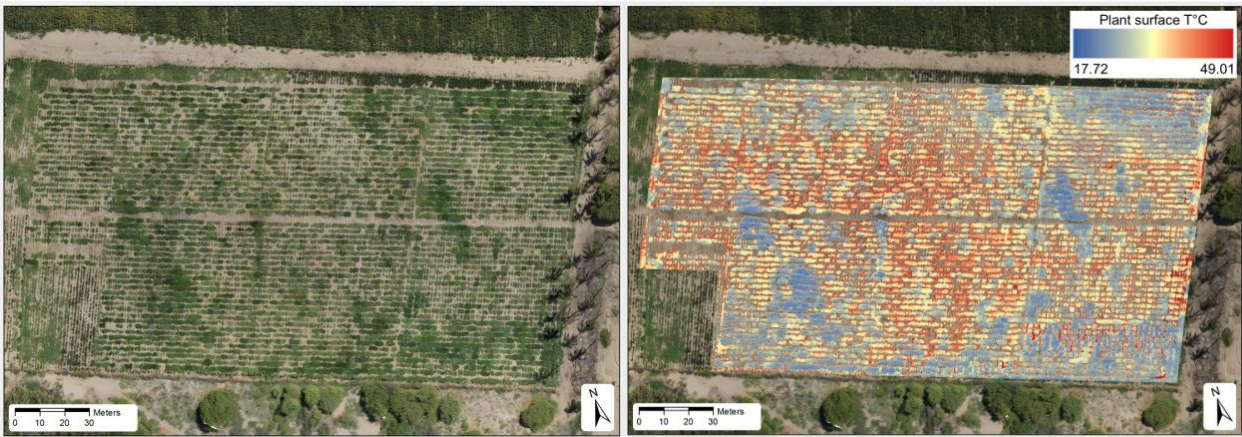


Figure 11: Images of sweet potato plots used to screen for heat tolerance, Piura, Peru 2014. Left: Aerial picture of sweet potato plot in the summer of 2014. Right: UAV-based thermal signatures of plant canopies at midday, 120 dap of the same plot (source: B. Heider, E. Faye, & O. Dangles; pers. comm.)

There is considerable genetic variation in heat stress response and a large fraction of the sweet potato germplasm is heat stress tolerant (i.e., 305 clones with yields >12.2 t/ha under stress; Figure 12). This indicates that a large pool of heat stress tolerant alleles is present and that large and sustainable genetic gains can be expected. This material is now being genotyped to identify these alleles or closely linked molecular markers.

2.1.5 Step 5. Developing management options for climate-smart varieties

Changed management will be an essential element of climate resilience. Farmers already have considerable experience responding to climate variability; they understand some of the interaction with varietal traits; we need to draw on this knowledge to guide breeding. Farmer participatory varietal

selection in the context of different management options will play a key role in breeding programs. Asfaw et al. (2015) identified four key challenges:

- Breeding informed by dynamics of adoption for heat or drought tolerance
- Determining drivers of the dynamics
- Understanding key processes in crop management related to climate: variety use, perception, and adaptation strategies
- Accounting for gender differences in knowledge and preferences for climate-related traits.

This is a critical area that is underdeveloped in RTB. One option to adapt to stress and reduced water availability in irrigated potato is partial root drying, which significantly reduces water utilization (Yactayo et al. 2013).

2.1.6 Step 6. Deployment (seed systems)

Climate change will put pressure on RTB seed systems, and faster rotation and uptake of new varieties will be necessary. These new varieties will need strong client orientation, given the strength of market and consumer preferences. Climate-smart but not “consumer smart” will not take us far.

Additionally, RTB seed systems themselves will need to adapt to climate change. For example, sweet potato seed systems often depend on the use of moist valley bottoms for vine multiplication during dry seasons to make planting material available at the beginning of rains (Gibson et al. 2016). Changes in rainfall and temperature may reduce the availability of suitable valley bottoms. One climate-smart alternative is the Triple S system (storage, sand, sprouting; Fig. 13). This is a root-based system that uses roots covered in sand to make it through the long dry season (Munyua 2013).

3 Conclusion

Climate-smart breeding adds an extra dimension to our objectives, as many other traits must be maintained and enhanced. Climate change is reinforcing the need for resistance to LB and viruses, heat tolerance, and earliness of tuberization. For potato, some particular issues include closer attention to the population range of DM content, which decreases with heat, and more vigilance toward undesirable glycoalkaloids that increase in some backgrounds with heat.

Therefore, climate-smart breeding means we need to do what we already do but faster, better, and smarter.

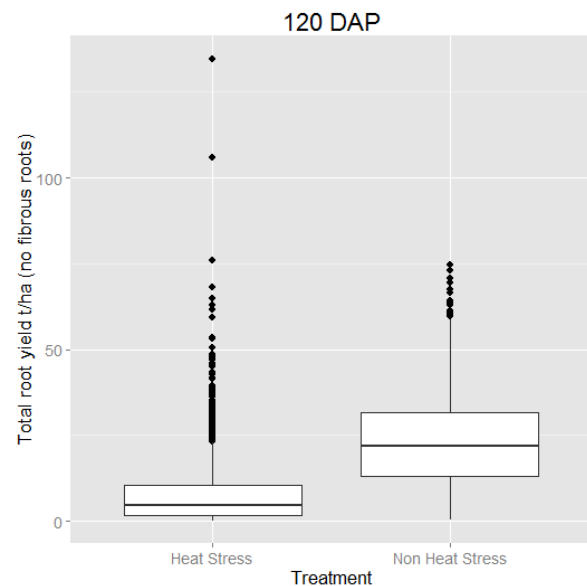


Figure 12: Total sweet potato root yield (t/ha), with and without heat stress (source: B. Heider, pers. comm.)



Figure 13: Climate-smart Triple S system (source: Munyua, 2013)

As higher levels of multiple traits are sought, robust consideration of quality is needed. Preventive or remedial measures have to be considered as well.

Climate change will widely impact crops. As a CRP, RTB can assume a key role in the response. Some of the areas where RTB can contribute include advocacy for climate-smart breeding and agriculture, jointly assembling big data, and monitoring and evaluation of progress. RTB is actively seeking partnership with the

Climate Change, Agriculture and Food Security CRP in the areas of downscaling climate change models, developing shared metrics to guide climate-smart breeding and testing options in climate-smart villages.

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References

- Asfaw A., Bonierbale M., Khan M.A., Integrative breeding strategy for making climate-smart potato varieties for sub-Saharan Africa. In: Low J, Nyongesa M, Quinn S, Parker M, eds. Potato and Sweetpotato in Africa. Transforming the value chains for food and nutrition security. Oxfordshire, UK: CABI International, 2015, 134–142, ISBN 978-1-78064-420-2
- Bonierbale M., Amoros W., Mejoramiento genético de la papa y resiliencia climática. Compendio de Resúmenes XXVII Congreso Asociación Latinoamericana de la Papa (ALAP). Panamá 2016.22 al 26 de Agosto, 2016, 30–32, ISBN: 978-9962-677-43-7
- Comas L.H., Becker S.R., Cruz V.M.V., Byrne P.F., Dierig D.A., Root traits contributing to plant productivity under drought. *Front. Plant Sci.*, 2013, 4, 1–16
- Gajanayake B., Reddy K.R., Shankle M.W., Quantifying growth and developmental responses of sweetpotato to mid- and late-season temperature. *Agron. J.*, 2015, 107, 1854–1862
- Gibson R., Phillips D., Lukonge E., Obong Y., Rwegasira G., Kalule S., Mushobozi W., Sweetpotato vines (planting material) as a business in Africa: Commercializing seed systems in Uganda and Tanzania. NRI publication, 2016
- Hallegratte S., Bangalore M., Bonzanigo L., Fay M., Kane T., Narloch U., Rozenberg J., Treguer D., Vogt-Schilb A., Shock Waves: Managing the Impacts of Climate Change on Poverty. Climate Change and Development Series. Washington, DC: World Bank, 2016, doi:10.1596/978-1-4648-0673-5
- Jarvis A., Ramirez-Villegas J., Herrera Campo B.A., Navarro-Racines C., Is cassava the answer to African climate change adaptation? *Tropical Plant Biology*, 2012, 5, 9–29
- Khan A., Sovero V., Gemenet D., Genome-assisted breeding for drought resistance. *Current Genomics*, 2016, 17, 330–342
- Kooman P.L., Haverkort A.J., Modelling development and growth of the potato crop influenced by temperature and day length: LINTUL-POTATO in A.J. Haverkort, D.K.L. MacKerron (Eds.), *Potato Ecology and Modelling of Crops Under Conditions Limiting Growth*, Kluwer Academic, Dordrecht, 1995, 41–60
- Munyua H., Sweetpotato planting material: the Triple S System - Storage, Sand, Sprouting. International Potato Center and Natural Resources Institute Publication, 2013 (Available from <http://www.sweetpotatoknowledge.org/wp-content/uploads/2015/12/TRIPLE-S-SYSTEM-SIDE2-ENGLISH.pdf>)
- Okonya J.S., Kroschel J., Incidence, abundance and damage by the sweet potato butterfly (*Acraea acerata* Hew.) and the African sweet potato weevils (*Cylas* spp.) across an altitude gradient in Kabale district, Uganda. *International Journal of AgriScience*, 2013, 3(11), 814–824
- Okonya J.S., Mujica N., Carhuapoma P., Kroschel J., Sweetpotato weevil, *Cylas puncticollis* (Boheman 1883). In: Kroschel J, Mujica N, Carhuapoma P, Sporleder M, eds. Pest distribution and risk atlas for Africa. Potential global and regional distribution and abundance of agricultural and horticultural pests and associated biocontrol agents under current and future climates. Lima: CIP, 2016, pp. 54–63, ISBN 978-92-9060-476-1, doi 10.4160/9789290604761-4
- Ravi V., Naskar S.K., Makesh Kumar T., Babu B., Prakash Krishnan B.S., Molecular Physiology of Storage Root Formation and Development in Sweet Potato (*Ipomoea batatas* (L.) Lam.). *J. Root Crops*, 2009, 35, 1–27
- RTB CGIAR Research Program on Root, Tubers and Bananas. 2016. Proposal 2017–2022. Lima: CIP
- Sparks A.H., Forbes G.A., Hijmans R.J., Garrett K.A., Climate change may have limited effect on global risk of potato late blight. *Glob. Change. Biol.*, 2014, 20, 3621–3631, doi:10.1111/gcb.12587
- Yactayo W., Ramírez D.A., Gutiérrez R., Mares V., Posadas A., Quiroz R., Effect of partial root-zone drying irrigation timing on potato tuber yield and water use efficiency. *Agric. Water Management*, 2013, 123, 65–70
- Washington R., New M., Hawcroft M., Pearce H., Rahiz M., Karmacharya J., Climate Change in CCAFS Regions: Recent Trends, Current Projections, CropClimate Suitability, and Prospects for Improved Climate Model Information. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark, 2012, (Available from <https://cgspace.cgiar.org/rest/bitstreams/14876/retrieve>)
- Wiebe K., Strategic foresight: Long-term projections from IFPRI, GFSF and AgMIP. Presented at the 12th Meeting of the Independent Science & Partnership Council held in Rome, 16 September 2015