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Report 508

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February 2013

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Executive summary

Recently, the concept of Climate Smart Agriculture (CSA) has been coined in an attempt to overcome the existing barriers among food security, adaptation of agriculture to climate change, and mitigation of greenhouse gas (GHG) emissions. Because the goals of CSA ultimately need to be achieved by farmers it is important to link and integrate CSA goals with Good Agricultural Practices (GAP). Although the general scope of GAP is clear, i.e. sustainable agricultural intensification, there is little common ground in what 'good' means in practice and how CSA goals should be addressed in GAP. The specific contexts, circumstances and capacities of countries determine how GAP is implemented in practice. Verhagen *et al.* (2013) developed a 'bottom-up' framework to integrate CSA goals and GAP consisting of different steps ranging from a description and assessment of current production systems, identification and evaluation of CSA options and GAP requirements, identification of institutional and financial barriers to the development of coherent strategies for implementation of promising CSA/GAP options.

Using the integrated framework, this report illustrates the integration of CSA and GAP in potato production systems in three contrasting economies with different biophysical and climatological conditions, i.e. The Netherlands (Flevoland) a high income economy in a temperate climate, South Africa (Sandveld) an upper-middle income economy in a Mediterranean climate, and Ethiopia (Rift valley) a low income economy in a semi-tropical climate. Related to the differences in economic development, physical conditions and expected impacts of climate change the cases illustrate the location-specific differences in current potato management, CSA options, and strategies to lift existing institutional and financial barriers hindering the realization of these options.

In general, global potato productivity is expected to benefit more from an increase in atmospheric CO_2 concentrations than productivity is reduced due to anticipated changes in climate conditions such as temperature and rainfall. The effect of climate change on the frequency and severity of weather extremes affecting potato productivity remains highly uncertain. Some plausible, but hard to verify effects associated with climate change such as changes in abiotic pressures are also uncertain. Despite these uncertainties, the anticipated impacts of climate change in the case study areas show a very divers picture: A decline in ground water resources (South Africa), shorter and drier growing seasons (Ethiopia) and increased frequency of wet soil conditions (The Netherlands) are among the most important effects associated with the expected change in climate in each of the cases.

Based on the smallest yield gap of the three cases potato production in Flevoland is most developed and also is least affected by expected climate change. More rainfall during planting and harvesting may require adaptation of mechanization to be better prepared for wetter soil conditions. An expected shorter and drier growing season may require adaptations of the current system in the Rift Valley, for example, through the introduction of irrigation. Such adaptation would allow a fundamental change in the potato systems as it allows producing potatoes during the dry season. If water resources are available and used with care such a transformation of the potato system potentially could create synergy: Lower biotic pressure in the dry season could result in higher potato yields than in the wet season. In terms of development, the Sandveld case takes an intermediate position but its current dependency on limited ground water resources and the anticipated decline in ground water resources probably poses the largest adaptation challenge of the three case study areas.

None of the case studies shows immediate and large potentials to address the mitigation agenda of CSA. This is largely related to the biological characteristics of the potato. About 80% of the potato biomass is harvested while for most cereals this percentage is about 50%. Also potato is less suitable for conservation tillage as crop yield is sensitive to proper soil preparation, while harvesting of the belowground production requires anyway soil disturbance. Only in an indirect way potato management can serve mitigation goals by more efficient use of fertilizers, irrigation water (energy use), pesticides and the inclusion of crops with high residual carbon biomass in potato rotations.

The Rift Valley shows the largest yield gap and attempts to close this yield gap will inevitably result in trade-offs among CSA attributes. To increase potato productivity in the Rift Valley considerably more (fossil) energy-demanding inputs will be required such as (nitrogen) fertilizers, pesticides and mechanization, which will increase GHG emissions

per unit of land. The challenge will be to achieve increased potato yields such that GHG emissions per unit of produce are more favourable compared to the current situation. Other options provide potential synergies, for example, improved irrigation (in Sandveld) may increase productivity, decrease water use (adaptation) and reduce nitrogen use (mitigation).

Institutional and financial barriers to the implementation of CSA options differ across cases and they are highly context specific. The case studies show that an R&D agenda for CSA should go beyond the common call for generic adaptations such as better adapted crop species and varieties and animal breeds. Equally important for such an agenda is the identification of very location-specific options and institutional and financial barriers to facilitate adoption of CSA options. Such options are not necessarily innovative from a global perspective as they often will have shown their suitability in other regions, and they should be the result of location-specific R&D agendas aimed at efficiency and productivity improvements as part of climate smart agriculture. The main contribution of CSA and the tested framework to GAP and development in general is that long-term thinking on productivity, adaptation and mitigation goals becomes an explicit and integrated component of sustainable intensification of agriculture.

1. General introduction

During the Conference on agriculture, Food security and Climate Change in The Hague, 2010 (http://www.afcconference.com/) the term 'Climate-Smart Agriculture (CSA)' has been coined to achieve the 'triple win' of sustainable development, adaptation of agriculture to climate change, and reduction of greenhouse gas (GHG) emissions. Although the link between sustainable development, agriculture and climate change is clear the issues are still addressed separately at national and international policy levels. In an attempt to overcome the existing barriers among these inter-related issues, the Food and Agriculture Organization (FAO) defined CSA as agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances achievement of national food security and development goals (FAO, 2010). Based on definitions of IPCC (2007), adaptation is here defined as the adjustment of the agricultural systems to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities, while mitigation is defined as the decrease in the intensity of radiative forcing in order to reduce the effects of global warming. The World Food Summit of 1996 defined food security as existing when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life (FAO, 1996).

For developing countries, which highly depend on agriculture and with a large share of food insecure people, the main objective of CSA is to improve food security, incorporating adaptation as required to meet this objective. In this context, opportunities for mitigation are usually considered as additional co-benefits that could potentially be financed by external mitigation funding sources (FAO, 2011). Hence, Climate Smart Agriculture seeks to enhance the capacity of the agriculture sector to sustainably support food security, incorporating the need for adaptation and the potential for mitigation into development strategies. The specific conditions, circumstances, and capacities within countries will define opportunities and barriers to implementation, and hence policy choices.

Climate Smart Agriculture builds on existing efforts to achieve sustainable agriculture intensification such as Good Agricultural Practices as part of FAO's Sustainable Agriculture and Rural Development (SARD) initiative (http://www.fao.org/sard/en/init/2224/index.html). The concept of Good Agricultural Practices (GAP) has evolved in recent years in the context of a rapidly changing and globalizing food economy and as a result of the concerns and commitments of a wide range of stakeholders about food production and security, food safety and quality, and the environmental sustainability of agriculture (FAO, 2007). GAP applies recommendations and available knowledge to addressing environmental, economic and social sustainability for on-farm production and post-production processes resulting in safe and healthy food and non-food agricultural products.

As for CSA there is no blueprint for GAP: The specific contexts, circumstances, and capacities of countries determine how GAP is implemented in practice. Because the goals of CSA ultimately need to be realised by farmers it is important to link and integrate CSA goals and Good Agricultural Practices. Verhagen *et al.* (2013) developed a framework to link CSA and GAP starting 'bottom up' with an assessment of current management practices at the farm level, identification of CSA management options and associated institutional and market barriers at higher scales to arrive at strategies required for implementation of GAP options that account for CSA goals. Because the elements of both CSA and GAP are context and location specific a number of case studies have been carried out to illustrate and test this framework. This report presents the case study on consumption potatoes, other reports deal with dairy (Groenestein *et al.*, 2013) and coffee. The case on consumption potatoes included three potato growing areas around the globe, Sandveld in South Africa, Flevoland in the Netherlands and the Rift valley in Ethiopia. The case studies are further introduced in Section 1.2 after a summary of the CSA/GAP framework in Section 1.1. This Chapter continues with a brief description of the expected impacts of climate change on potato production and Good Agricultural Practices in consumption potato production. Subsequent chapters describe the Sandveld case, Flevoland case and Rift Valley case, respectively, while the report synthesises the results of the cases studies in a concluding chapter.

1.1 CSA/GAP framework

Verhagen *et al.* (2013) developed a step-wise framework to link CSA and GAP starting 'bottom up' with an assessment of current management practices at the farm level, followed by the identification of CSA options that meet GAP requirements. Subsequently, the framework addresses institutional and market barriers (at higher scales) to adopt new management options. The final step in the framework comprises the development of enabling strategies to overcome barriers and to implement management options. Figure 1.1 illustrates the steps of the framework to better link CSA and GAP.

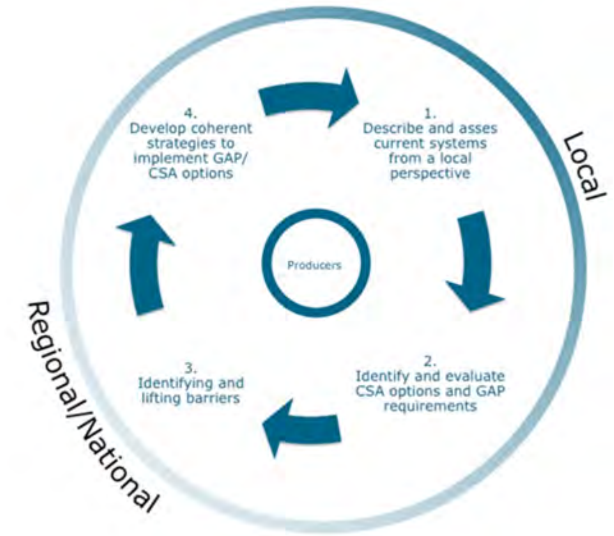

Figure 1.1 Framework for linking Climate Smart Agricultural strategies and Good Agricultural Practices (Verhagen et al., 2013).

The local context shaped by history, culture, socio-economic, legal and biophysical characteristics resulted in characteristic agricultural systems and practices. Acknowledging the local specific character of agricultural systems the CSA/GAP framework begins with an assessment of the current agricultural system and their vulnerability to climate change. Understanding of the current and expected future situation forms the basis for the identification of management options to increase and stabilize productivity and to develop potential adaptation and mitigation options.

Based on understanding of the current situation, the second step focuses on the identification of management options that serve both CSA goals and GAP requirements. Important conditions in CSA and GAP are that such options maintain or increase production levels to secure farm income and food security goals. Such management options do not necessarily have to be developed from scratch. In most cases management options will have proven their feasibility and potentials in other situations, but they can be considered new for the situation under study. Further, compliance with GAP will vary depending on the biophysical conditions, targeted product markets and local experience of farmers. An array of potential GAP/CSA options can be identified, which will need to be evaluated with respect to their contribution to food security, mitigation and development objectives. Such evaluation is needed to identify synergies and trade-offs. How to deal with trade-offs, e.g. production vs. GHG emissions, will strongly depend on priorities of national, local and value chain stakeholders. Prioritisation need to be set in consultations with relevant stakeholders.

The next two steps of the CSA/GAP framework address scales beyond the local level as they involve the identification of institutional and financial barriers impeding the adoption of options and the strategies to overcome such bottlenecks. Both steps require a good understanding of the socio-economic, institutional and political environment in which farmers operate. Only when the barriers are addressed through appropriate strategies the earlier identified management options may become within reach of farmers.

The framework hinges on the concept that agricultural systems are dynamic and that new developments will impose new barriers requiring new strategies enabling the implementation of CSA options. Similarly, the iterative framework acknowledges that if new insights and knowledge is available new options may emerge that need to be evaluated with respect to their contribution to CSA goals. The framework is limited to the production aspects of GAP, which generally also includes post-harvest aspects.

1.2 Introduction to the case studies

In this report three potato cases are described and used to illustrate the linking of CSA and GAP using the framework presented in Section 1.1. The three potato cases are in three contrasting economies and with different biophysical and climatological conditions, i.e. The Netherlands (Flevoland) a high income economy in a temperate climate, South Africa (Sandveld) an upper-middle income economy in a Mediterranean climate, and Ethiopia (Rift valley) a low income economy in a semi-tropical climate.

Related to the differences in economic development, physical conditions and expected impacts of climate change the cases illustrate the differences in current potato management, identification of different management options in potato systems, existing barriers to the realization of these options and directions for the development of strategies to align GAP/CSA practices. The last two steps of the framework are addressed jointly in each case to avoid overlap.

In the description of the cases we follow the steps as described in the framework (Chapter 1). We qualitatively assess current potato management practices in the three case study areas with respect to the attributes of climate smart agricultural practices, i.e. their contribution to productivity, adaptation and mitigation (step 1 of framework). Based on understanding of current management and context a number of management options are identified and prioritized (step 2 of framework). Institutional and financial barriers to the adoption of prioritized management options are identified and discussed in the context of enabling strategies discussed (step3 and 4 of framework).

Table 1.1. Major management operations in potato cultivation.

Management operation	Description
Variety selection	The genetic characteristics of varieties determine the production potential under given conditions, sensitivity to stresses (diseases, drought etc.) and market acceptance.
Rotation	The practice of growing different types of crops in succession on the same land mainly to preserve the productive capacity of the soil, and abate soil born pests.
Land preparation/tillage/ planting	The practice to maintain proper soil aeration, shaping beds to allow space for maximum tuber growth and minimize tuber greening, control weeds and if applicable to establish irrigation furrows. In potato, tillage is often combined with planting.
Water management	Water management including prevailing rainfall is one of the most important factors determining yield and quality of potatoes. Many tuber disorders and diseases are related to excessive amounts of water or poor temporal distribution of water.
Nutrient management	Proper nutrition is crucial in determining potato yield and quality, as well as the ability of the crop to withstand pest, environmental, and other stresses.
Crop protection	The application of chemical, physical and biological methods to minimize the yield-reducing effects from weeds, pests and diseases.
Harvest	The manual or mechanical removal of the tubers from the field, often preceded by one or more mechanical, chemical or physical operations to kill the vines

Emphasis in the cases is on steps 1 and 2 of the framework as here the goals of CSA and GAP mostly integrate. Because of differences in availability and quality of data and information the detail of description varies per case.

Management is the main instrument of farmers to achieve production, socio-economic and environmental goals, therefore, an overview and description is given of the major management operations in the production of consumption potatoes. Table 1.1 describes the major management operations in potato cultivation, which potentially affect attributes of climate smart agriculture.

1.3 Climate change impacts on potato production

The impacts of climate change on potato yields will vary per region, but in general the impacts of changing rainfall and temperature will be positive in temperate regions and negative in sub-tropical and tropical regions (Haverkort & Verhagen, 2008). Impacts of higher CO_2 concentrations on potato yield and resulting water use efficiency are positive across most regions of the world (Jaggard *et al.*, 2010): potato yields may increase by 28% in 2050 compared to 2007 potato yields. Indirect impacts of climate change such as saline intrusion in coastal areas may hamper potato production and irrigation potential. Changes in pest and diseases as potential yield reducing factors are critical for the success of the potato production system but their impact will be very local and difficult to assess.

1.4 Good Agricultural Practices in potato production

As a contribution to the United Nation's International Year of the Potato in 2008 the International Potato Centre (CIP) drafted guidelines for sustainable potato production in developing countries (Lutaladio *et al.*, 2009). It defines GAP as principles and codes of practice that are applied to on-farm production and post-production processes and aim at ensuring safe and healthy food and non-food agricultural products, while taking into account economical, social and environmental sustainability.

The guidelines present a compilation of potato management practices that have supported to increase potato production and productivity in tropical and subtropical developing countries. They serve as guiding principles which need to be refined to address particular conditions in specific locations. The guidelines identify 11 areas of sustainability, each with a set of specific good agricultural practices: a) Biodiversity and varieties, b) seed production and seed quality, c) seed systems, d) Soil health and fertility management, e) nutrient management, f) soil conservation, g) pest management, h) water management, i) post-harvest management, j) value addition and markets, and k) farmers' health, safety and welfare. Six of these 11 areas are directly related to and are covered by the major management operations in potato cultivation as described in Table 1.1. Five other areas of sustainability can be considered boundary conditions (e.g. Farmers health, safety and welfare) or are not directly related to field management operations of consumption potatoes and, therefore, are outside the scope of the CSA/GAP framework. These sustainability areas include seed production and seed quality, seed systems, post-harvest management, and value addition and markets. Although these areas are largely outside the scope of the framework yet parts are covered by the major management operations such as the selection of varieties most preferred by consumers that is considered GAP within the sustainability area of value addition and markets.

2. South-Africa–Sandveld

2.1 General introduction

One of the major potato areas in South Africa is the semi-arid Sandveld region in the South-west near the Atlantic coast (Franke *et al.*, 2011). About 14% of the national potato production comes from this region (6,600 ha under potatoes), and approximately 75% of the production consists of potatoes for consumption and the rest for seed (http://www.potatoes.co.za/; Knight *et al.*, 2007). Nearly 15% of the produced consumption potatoes are processed.

Climate data are given in Table 2.1 and information on typical soils used for potato cultivation in Sandveld is shown in Table 2.2 (Franke *et al.*, 2011). In general, average rainfall is low with only 298 mm per year, while the soils are extremely sandy and very low in organic matter content. Associated with the low clay content of the Sandveld soils they have a low retention capacity, low cation exchange capacity and low retention of nutrients, high leaching potential, low buffer capacity and high acidity, high wind erosion potential and moderate compaction potential (Knight *et al.*, 2007).

Table 2.1. Climate in Sandveld (Graafwater weather station), average of 1990-2008.

Month	Monthly rainfall (mm)	Daily minimum temperature (°C)	Daily maximum temperature (°C)	No. of days with average temperature < 12 °C	No. of days with average temperature > 32 °C	Radiation (MJ $m^{-2}d^{-1}$)
January	6	15.0	31.3	0	13	27
February	6	15.4	31.6	0	12	23
March	7	14.4	30.5	0	11	20
April	25	12.7	27.3	0	7	14
May	41	10.7	23.7	2	3	11
June	49	8.7	20.4	6	0	8
July	56	8.1	20.0	9	0	9
August	39	7.5	20.2	9	0	11
September	26	8.9	23.2	2	3	15
October	18	10.8	26.0	0	5	19
November	12	12.5	27.7	0	6	22
December	13	14.4	29.7	0	9	23

Sandveld forms part of the western lowland area of the Greater Cederberg Biodiversity Corridor. Ploughing of natural habitat for potato production and extensively produced rooibos tea has led to large scale conversion of this important coastal habitat, making it the second most highly threatened ecosystem of South Africa. At least 58 rare and threatened plant species and a large number of threatened animals occur in Sandveld. The Verlorenvlei in Sandveld is one of the most important estuarine systems in the Western Cape and one of the largest natural wetlands along southern Africa's west coast (Shippey *et al.*, 2009). This freshwater coastal lake is classified as a Ramsar site since 1991. Several dams disrupt hydrological fluctuations, cause siltation and prevent fish migration. Land surrounding the wetland is privately owned and intensive farming practices pose several threats to the surrounding vegetation (grazing, invasive alien vegetation and abstraction of groundwater). Typically, this inland wetland lake is fed by groundwater during the dry season (Belcher *et al.*, 2011).

Table 2.2. Soil physical and water holding characteristics of the topsoil (0-25 cm) and sub soil 25-50 cm) of a soil typically used for potato production in Sandveld, South Africa (Franke et al., 2011).

Soil property	Soil depth (cm)	
	0-25	25-50
Sand (0.02-2 mm) (%)	94.7	94.7
Silt (0.02-0.0002) mm) (%)	0.4	2.1
Clay (<0.0002 mm) (%)	2.1	1.0
Volumetric field capacity (m3 m-3 at -5 kPa)	5.32	4.54
Wilting point (m3m-3 at -1500 kPa)	1.88	1.25
Total plant available water (mm) in 0-500 mm root zone	17.2	16.5
Organic matter content (%)	0.25	0.22

In general, Sandveld is a biodiversity rich and environmental fragile area. Potato production completely depends on irrigation water that is abstracted from shallow to deep groundwater. The extreme sandy soils require careful water and nutrient management to avoid wind erosion and leaching of salts and nutrients to groundwater. Although the area with center pivot irrigation systems has increased over the years to more than 30,000 ha, the production (area) of potatoes has remained fairly stable at around 6,500-7,500 ha. This apparent discrepancy is ascribed to the general belief that 'new' land ensures higher yield levels due to the absence of soil borne pathogens (Knight *et al.*, 2007). This implies that the length of common potato rotations is about 5 years, while the land is left fallow during the years between potato crops.

Possibilities for expansion of the irrigated area are determined by the capacity of underground water reserves. Approximately 47 Mm3 per year or 25% of the annual groundwater recharge is currently abstracted for potato production in Sandveld (Knight *et al.*, 2007). Since evidence-based limits for safe abstraction are not (yet) available it is not possible to evaluate this percentage in terms of sustainability. However, some catchments in Sandveld have abstraction rates of 65 to 120% which certainly indicates at unsustainable practices (Knight *et al.*, 2007).

Archer *et al.* (2009) indicate that climate change for the area points to increased temperatures, lower rainfall during critical months and reduced groundwater recharge and a likely increase in heat and water stress risk. They further conclude that these changes are important for potato farming in the Sandveld region, current water demand is already high and depends heavy on irrigation using groundwater. Increased temperatures will increase irrigation requirements, while decreased rainfall will decrease groundwater recharge.

2.2 Assessing current potato systems in Sandveld

Annually, about 6,600 ha of potatoes are harvested in Sandveld with average yields around 40-45 t ha^{-1} with little difference between seed and consumption potatoes (Franke *et al.*, 2011).

Because of the favourable climate, potatoes can be grown year-round, but there are two peak planting periods, one from January to April (summer) and one from May to December (winter). The summer crop is marketed from October to April, while the winter crop from May to October (Figure 2.1). Current production units (farms) are large (average 3,271 ha of which on average 352 ha under irrigation) and fairly modern using overhead center pivot sprinkler systems for irrigation of the potato crops.

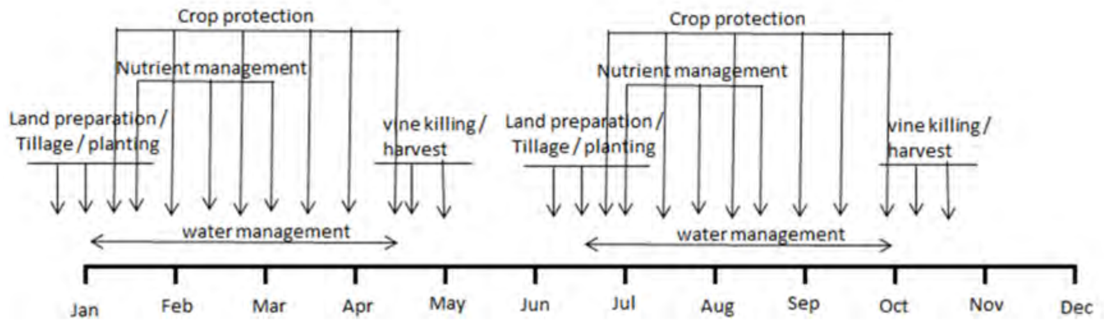

Figure 2.1. Typical sequence of management operations of a summer and winter potato crop in Sandveld.

Current information on potato management in Sandveld is compiled in Table 2.3. Irrigation water management is the most important management operation under the dry conditions of Sandveld and is required throughout the growing season and only stops just before vine killing. Other operations such as nutrient applications can be combined with irrigation as fertigation. Crop protection generally is maintained over a longer part of the growing season than nutrient management operations.

Table 2.3. Characteristics of current potato management in Sandveld, South Africa. (Source: Knight et al., 2007; Franke et al., 2011; PSA, 2011).

Management operation	Current status
Variety selection	Most used varieties: BP1, Up-to-date, Buffelspoort, Vanderplank and Columbus
Rotation	Based on the area under irrigation (30,740 ha), the rotation frequency is just below 1:5. Generally, the potato land is left fallow in between potato years.
Land preparation/ Tillage/ planting	Mechanised
Water management	Centre pivot systems using mainly groundwater between 0.5 and 100 m below ground level. Total irrigation water use in Sandveld is 46.9 Mm^3, which corresponds roughly with 6,900 m^3 ha^{-1} (690 mm).
Nutrient management	Depending on different information sources N, P_2O_5 and K_2O fertilizer use varies between 259-306, 128-140 and 379-406 kg ha^{-1}, respectively
Crop protection	Often weekly control of *Phytophtera* and *Altenaria*
Harvest	Frequently semi-manual; windrowing and hand harvesting

In Table 2.4 current potato management practices in Sandveld is assessed with respect to the attributes of climate smart agricultural practices, i.e. their contribution to productivity, adaptation and mitigation.

Table 2.4. Assessment of current potato management in Sandveld with respect to productivity, adaptation and mitigation.

Major management operations	Attribute of Climate Smart Agriculture		
	Productivity	Adaptation	Mitigation
Variety selection	Genetics of plant material determine production potential. Given the simulated yield gaps (Figure 2.2) there is still scope for productivity improvements using current varieties.	Genetics of plant material determine robustness to environmental stresses. Especially, adaptation to heat stress is relevant under Sandveld conditions.	Potato contributes little (carbon) biomass to the system as most is harvested. High yielding varieties require high inputs of irrigation water and nitrogen, which both contribute to GHG emissions.
Rotation	Land is left fallow after growing potatoes, while the rotation frequency of consumption potato is relatively wide, which is favourable for high yields.		Fallow vegetation will add to the soil carbon stocks, but these stocks may be released rapidly after tillage of the next potato crop.
Land preparation/ Tillage	Conventional tillage may favour top soil losses due to wind erosion possibly affecting crop yields in the long-term.		Conventional tillage has a negative effect on SOM, but current SOM content is already very low in Sandveld. It is uncertain whether current tillage affects SOM levels. Tillage is an energy-demanding operation increasing GHG emissions.
Water management	Without irrigation water no potato production is possible in Sandveld. Hence, irrigation is of utmost important for current productivity.	Irrigation is an essential adaptation practice under dry conditions of Sandveld.	Irrigation requires energy and therefore contributes to GHG emissions.
Nutrient management	Proper nutrient management is crucial for realising high yields at the poor soils of Sandveld. Current nutrient rates are rather high but maybe required to realise high yields at sandy soils of Sandeveld.	Nutrient management reduces the impact of environmental stresses.	Fertilizer production requires energy. Fertiliser use contributes to N_2O emissions.
Crop protection	Potato is relatively susceptible to pests and diseases and crop protection is required to guarantee high yields.	Crop protection reduces the impact of biotic stresses.	Production and application of crop protection agents requires energy and this increases GHG emissions.
Harvest			Machine harvesting results in GHG emissions

2.3 Identification of CSA options and GAP requirements

Model simulations show that potential yields in Sandveld vary between 52 and 95 t ha^{-1} depending on the month of planting (Figure 2.2; Franke *et al.*, 2011). Under non-limited water supply conditions, yields are highest with planting in August-November and lowest with planting in February-June. In the summer (January-April) high temperatures may reduce production while in the winter (May-December) low radiation and sometimes low temperatures limit potato production. This implies that current production levels (40-45 t ha^{-1}) represent approximately 80% of the yield potential in the summer period and 45% of the yield potential in the winter period.

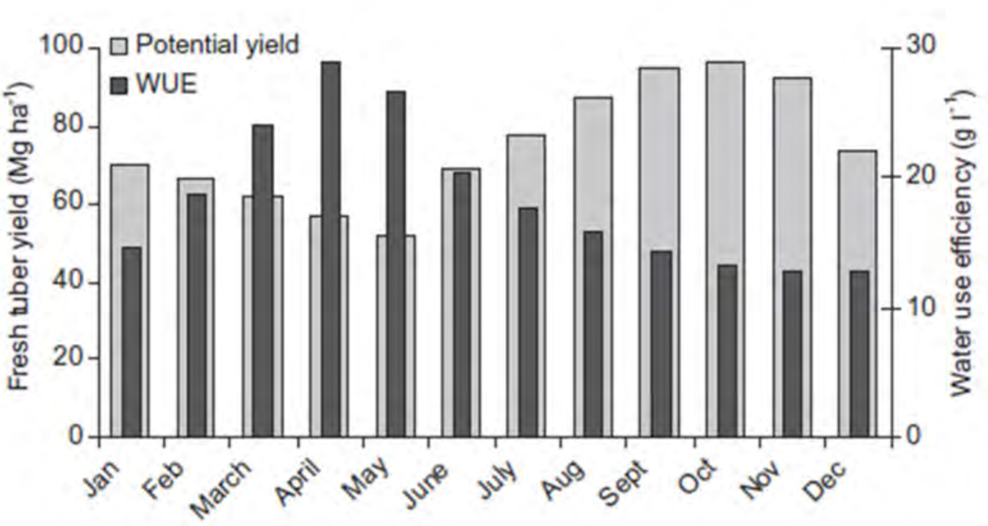

Figure 2.2. Simulated potential yield (left y-axis) and water use efficiency based on evapotranspiration by the crop and soil (WUE) (right y-axis) per planting month. (Franke et al., 2011).

In contrast with the simulated yields, which are highest during the winter period, water use efficiencies are highest during the summer period (Figure 2.2).

Haverkort *et al.* (2013) downscaled the output of six different coupled climate models of Assessment Report Four of the Intergovernmental Panel on climate change to assess the impact on potato production and related water use efficiency by the year 2050 in Sandveld. All the projections are based on the A2 scenario of the Special Report on Emission Scenarios (SRES). Using a crop growth model the effects on potato yields were estimated based on projected changes in temperature, solar radiation, precipitation and evapotranspiration and a radiation use efficiency which was dependent on carbon dioxide concentration. Based on these climate projections, summer potato crop in Sandveld is expected to face more frequent maximum temperatures exceeding 30°C, which will limit photosynthesis and thus productivity. Low rainfall will further decrease a bit but variation among the years is much higher than for temperature. Also radiation tend to decline by a few per cent in the year 2050 compared to the base year 1961. However, under unlimited water supply (irrigation), any negative effects of climate change on the production potential of potatoes are more than compensated by the increase in atmospheric CO_2. The potato winter crop (planting March 15) still is able to reach 58 t ha^{-1} and the summer crop (planting September 15) 98 t ha^{-1}. These yields are comparable with the potential simulated yields using historical weather (Figure 2.2).

The Biodiversity best practices initiative (BBI) in Sandveld has set guidelines for biodiversity-friendly potato production and it rewards farmers for conforming to the set of recommended practices (Knight *et al.*, 2007). Participation of farmers, although promoted by branch organisations, NGOs and environmental organizations, is on voluntary basis. Record keeping of inputs and outputs including corresponding dates, management plans needs to be done by the farmer and a summary is handed over to an auditing agent appointed by Potatoes South Africa (branch organization) and CapeNature, a public institution for biodiversity conservation. The BBI guidelines provide local specific directions to improve crop management and resource use efficiencies as part of GAP (Table 2.5).

Table 2.5. Guidelines according to the Biodiversity best practice initiative (BBI). (Based on Knight et al., 2007).

Management operation	Good Agricultural Practice
Variety selection	Not addressed in BBI
Rotation	Use cover crops
Land preparation/Tillage	- Knowledge about the soil (soil assessment) - Buffer strips of at least 50 m (100 m preferred) recommended to reduce risk of spray drift, erosion and leaching of nutrients (Knight *et al.*, 2007). - Avoid sites where extreme wind erosion is prevalent. - Avoid planting and harvest times that correspond with strong windy periods.
Water management	- Do not over irrigate to leach out salts from the soil as this practice may contaminate groundwater. - Maximum level at which water should be used: 270 mS/m (EC), 400 mg/l (Na) and 600 mg/l (Cl) - Professionally designed irrigation system for the land where it is used, and proper maintenance of the system. - Properly adjusted irrigation equipment (nozzles, even pressure, etc.) and pump recording on a monthly basis as part of the Water Act. - Avoid irrigation under windy conditions.
Nutrient management	- Adequate soil sampling (nutrients, pH and salinity) - Adjust nutrient requirements to the crop needs in each growth stage and soil properties. - Use fertigation. - If possible use organic nutrient sources to supplement inorganic fertilizer programs
Crop protection	- Apply IPM cultural, physical and biological principles including due attention to variety choice, planting time, ridging, crop rotation, mid-summer break to control viruses, etc.

In addition to the GAP related to the crop management at field level also local specific GAP guidelines been described in the BBI for farm and landscape level such as road planning, water abstraction and storage, fire corridors, game management, waste management and invasive plant species, and fuel and liquid fertiliser storage on farm (Knight *et al.*, 2007).

Based on the expected manifestation of climate change in Sandveld the following gross list of CSA options for the various management operations can be identified (Table 2.6).

Table 2.6. Different CSA options for the various management operations in potato production in Sandveld. Between brackets the major CSA attribute(s) addressed by the option.

Management operation	Options
Variety selection	- Development of potato varieties with increased heat tolerance, especially with respect to tuber initiation and development which are more sensitive than photosynthesis. (adaptation) - Development of varieties with increased drought tolerance, which would potentially reduce water (and thus energy) needs. (adaptation/mitigation) - Development of varieties which are more resistant to pests and diseases as their pressure most likely increases under elevated temperatures (adaptation).
Rotation	- Incorporation of crops with high residual biomass, which potentially enriches SOM and increases resource use efficiencies. (productivity/mitigation) - Shift in crop calendar of potato to other months with more favourable temperatures. (productivity/adaptation)
Land preparation/ Tillage	- Though conservation tillage is difficult in potatoes, certain practices such as application of mulch to lower soil temperature and increase water retention maybe considered. (adaptation/mitigation)
Water management	- More efficient irrigation methods such as drip. productivity/adaptation) - Sensor based technologies to better match crop water requirements and water supply. (productivity/adaptation) - Decision support tools to schedule irrigation. (productivity/adaptation)
Nutrient management	- Soil sampling before planting to better identify crop fertility needs. (productivity/mitigation) - More efficient irrigation methods (e.g. drip) would allow also more efficient fertigation methods. (productivity/mitigation) - More use of fertigation methods enabling to match better temporal nutrient demand and supply and this reduce fertilizer use. (productivity/mitigation) - Using organic fertilizers may reduce the use of inorganic (and energy-demanding) fertilizers. (mitigation)
Crop protection	- More pest and disease resistant varieties would enable to use less crop protection agents. (adaptation) - More efficient water management would reduce pest and disease pressure. (adaptation) - Decision support tools to increase efficacy of crop protection measures. (adaptation)

Priority should be given to climate smart changes in water management practices considering the dependence of potato production in Sandveld on groundwater, the emerging tension on scarce water resources between potato production and nature interests (Knight *et al.*, 2007), and expected increase in rainfall variability and higher temperatures inducing higher evapotranspiration rates and reducing groundwater recharge rates (Archer *et al.*, 2009). The identified CSA options for water management in Table 2.6 represent synergy as they both have the potential to increase productivity and adaptation to the anticipated changes in climate conditions in Sandveld. Indirect the proposed water management options may also contribute to mitigation as they have the potential to reduce nutrient use as lower water inputs may result in less leaching losses. Further gains in nutrient efficiencies and productivity can be achieved through fertigation using drip irrigation.

2.4 Barriers and strategies to implement CSA options

One of the major uncertainties in the analysis is the lack of quantitative data on the use of groundwater by the agricultural sector (Shippey *et al.*, 2009). This also hampers discussions and dialogues between the agricultural sector and other sectors, particularly the nature and environmental parties, and creates a status qua in which parties do not want to act and invest in options that potentially provide synergies (Table 2.6). Institutional arrangements need to be developed to measure systematically groundwater recharge and to control water abstraction for irrigation, for example, beginning with a better monitoring of ground water levels by the responsible public authorities in the area. This would allow more transparent discussions and well-informed decisions. In the end detailed groundwater level and quality monitoring can be used to act timely when threshold levels are exceeded, or used for regulation purposes through for example: water licencing, water quota's and water pricing.

The identified CSA options for Sandveld are not necessarily innovative and new as they are being used implemented in other potato growing areas of the world but they do require substantial investments from both the public and private sector. Therefore, the financial sector should enable the potato industry in Sandveld to invest, for example, in the transition from centre pivot irrigation to drip irrigation. The public sector needs to invest in existing or new institutions to monitor ground water levels and if appropriate enforce regulations related to water abstraction and water quality.

3. The Netherlands–Flevoland

3.1 General introduction

Flevoland province is one of the major potato production areas (20,000 ha in 2009) in the Netherlands, producing approximately 13% of the total national production volume. Roughly two-third of the potato production in Flevoland is used for consumption, while the rest for potato seed. The average yield of consumption potatoes was 55.3 t ha^{-1} and of seed potatoes 41.2 t ha^{-1} in 2009 (CBS, 2012).

Average annual rainfall is about 848 mm in Flevoland (Table 3.1), while the soils are predominantly very fertile young clay soils due to the recent polder reclamation of Flevoland (Table 3.2). In general, soils are medium to heavy clay soils with relative low water tables allowing for capillary rise of groundwater to the root zone.

Table 3.1. Climate in Flevoland (Lelystad weather station), average of 1981-2010 (KNMI, 2012).

Month	Monthly rainfall (mm)	Daily minimum temperature (°C)	Daily maximum temperature (°C)	No. of days with average temperature < 0 °C	No. of days with average temperature > 30 °C	Radiation (MJ $m^{-2}d^{-1}$)
January	71	0.1	5.2	13	0	2.4
February	53	-0.1	5.8	12	0	4.6
March	69	2.0	9.4	8	0	8.6
April	46	4.2	13.5	3	0	14.1
May	63	7.9	17.4	0	0	17.8
June	70	10.4	19.6	0	0	18.8
July	86	12.6	22.0	0	1	18.3
August	84	12.4	22.0	0	1	15.2
September	75	10.2	18.6	0	0	10.3
October	81	6.9	14.2	1	0	6.1
November	76	3.7	9.2	5	0	2.7
December	73	0.8	5.6	13	0	1.7

Table 3.2. Soil physical and water holding characteristics of the topsoil (0-250 mm) of a soil typically used for potato production in Flevoland, the Netherlands.

Soil property	%
Lutum (< 0.002 mm)	14
Organic matter content	2

Table 3.3 provides information on the monthly exposure of potatoes in Flevoland to unfavourable climate conditions negatively affecting potato yields. See Appendix I for a more information on these climate conditions and an explanation how these conditions affect potato productivity (Schaap *et al.*, 2009).

Table 3.3. Frequency of occurrence (number of days) of unfavourable climate conditions for potato in Eelde as calculated by KNMI for the period 1976-2005 (Schaap et al., 2009). See Appendix I for further explanation.

Climate condition: possible impact	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Early prolonged rainfall: delayed planting	13	5	5	0						5	8	9
Heavy rainfall: limits field accessibility and induces tuber decay					0	0	0	2	1			
Heat wave: inducing secondary tuber growth							2	6	0			
hot and wet: inducing diseases							0	1	0			
Extreme heat: killing of canopy						0	0	0				
Frost: killing seed potatoes in spring				0	0							
Late prolonged rainfall: damage to tubers								5	4	5		
Warm winter: rotting of tubers and early sprouting	0	0	3									0

Some climate factors are currently not relevant for current potato production in Flevoland (e.g. extreme heat) but they may become relevant in the future under changing climate conditions. Similarly, the frequency of other climate conditions (such as warm winter) may increase in the future affecting potato yields stronger than in the past.

3.2 Assessment of current potato systems in Flevoland

Average yields of consumption potatoes were 55.3 t ha^{-1} and of seed potatoes 41.2 t ha^{-1} in 2009 (CBS, 2012). Potatoes are grown once a year in Flevoland from April to October. Production units are quite large for Dutch conditions, i.e. arable farms measure on average 56 ha in Flevoland and about 30% is under potatoes indicating a rotation frequency of almost 1:3. Hence, potato is intensively produced which is related to its profitability. Irrigated production is not standard and if practiced it is used supplementary in a low frequency.

Table 3.4. Characteristics of current potato management in Flevoland, the Netherlands (KWIN 1992; 2012).

Management operation	Current status
Variety selection	Agria, Asterix, Bintje
Rotation	Often grown in combination with winter wheat and sugar beet (1:3) or with an additional crop (onions, vegetables) (1:4)
Land preparation/Tillage/planting	3 to 4 mechanised operations (about 250 l of fuel and lubricants are used for all mechanised field operations)
Water management	Incidentally irrigation applied with overhead water guns
Nutrient management	On average 252 kg N ha^{-1}, 105 kg P_2O_5 ha^{-1}, 180 kg K_2O ha^{-1}
Crop protection	High use frequency, especially to control late blight
Harvest	Mechanised

In Table 3.5 we assess current potato management practices in Flevoland with respect to the attributes of climate smart agricultural practices, i.e. their contribution to productivity, adaptation and mitigation.

Table 3.5. Assessment of current potato management in Flevoland with respect to productivity, adaptation and mitigation.

Management operation	Attribute of Climate Smart Agriculture		
	Productivity	Adaptation	Mitigation
Variety selection	Genetics of plant material determine production potential. Given the relatively small yield gap new varieties are needed for achieving productivity improvements.	Genetics of plant material determine robustness of varieties to environmental stresses. Especially, resistance to drought, inundation and plagues are relevant for Flevoland conditions	Potato contributes little carbon to the system as most biomass is harvested. High yielding varieties require high inputs of nitrogen, which contributes to GHG emissions.
Rotation	Rotation frequency of potato is relatively narrow for consumption potatoes but considering the small yield gap current productivity is not much affected.	Potato is the major crop in current rotations and therefore of major importance for the economic resilience of the farming systems	Especially, wheat and sugar beet provide carbon input to current rotations with potato.
Land preparation/ Tillage	Conventional tillage stimulates mineralisation and SOM decomposition thus releasing nutrients for crop uptake.	Proper tillage is required to reduce risks for inundations on the clay soils of Flevoland.	Tillage has a negative effect on SOM content. Tillage is an energy-demanding operation increasing GHG emissions.
Water management	Because of favourable soil water-holding capacity irrigation is hardly required for high yields. Therefore, irrigation is not common. Drainage at the start and end of the season may pose problems at heavy clay soils of Flevoland.	Because of the absence of irrigation equipment Flevoland is poorly prepared for extreme drought Extreme rainfall can pose inundation problems at harvest or cause delayed planting.	
Nutrient management	Proper nutrient management is crucial for realising high yields. Recent reductions in fertilizer use show that efficiency improvements are possible.	Nutrient management reduces the impact of environmental stresses.	Fertilizer production requires energy and therefore contributes to GHG emissions. Fertilizer use contributes to N_2O emissions.
Crop protection	Potato is sensitive to pests and diseases and crop protection is required to guarantee high yields. Crop protection is well-advanced but control of late blight remains crucial.	Crop protection reduces the impact to biotic stresses.	Production and application of crop protection agents requires energy and this increases GHG emissions.
Harvest		Harvesting can be problematic under high rainfall conditions.	Machine harvesting results in GHG emissions

3.3 Identification of CSA options

Based on crop simulations, the yield gap between actual and potential potato yields has been estimated at about 25-30% for Flevoland, i.e. the difference between current yields (55 t ha^{-1}) and potential yields (70 t ha^{-1}) is about 15 t ha^{-1} (Wolf *et al.*, 2011). The same authors also investigated the potential effects of climate change on the potential yields of various crops among others potato by the year 2050. Two contrasting SRES scenario were used, i.e. A1FI and B2 combined with scenarios of the KNMI: A1FI was associated to the W and W+ scenarios (+2°C) and B2 to the G and G+ (+1°C) scenarios of KNMI (Van den Hurk *et al.*, 2006). Main conclusions are:

- Change in climate and increase in atmospheric CO_2 in the year 2050 result in yield increases for potato in Flevoland in all climate change scenarios; for the W/W+ scenario the yield increases up to 10% compared to current yields.
- Increases in yields in 2050 compared to current yields are mainly caused by the positive effect of the increase in atmospheric CO_2, whereas this effect is partly counteracted by the negative effect of temperature rise. Hence, the yield increases for the A1-W/W+ scenarios with a higher CO_2 concentration appear to be only slightly higher than those for the B2-G/G+ scenarios.

Table 3.6. Different CSA options for the various management operations in potato production in Flevoland. Between brackets the major CSA attribute(s) addressed by the option.

Management operation	Options
Variety selection	- Development of potato varieties with higher production potentials than current varieties. (productivity) - Development of varieties with increased tolerance to temporary wet soil conditions. (adaptation) - Development of varieties which are more resistant to pests and diseases as their pressure most likely increases under elevated temperatures and wetter conditions. (adaptation)
Rotation	- Incorporation of crops with high residual biomass, which potentially enriches SOM and increases resource use efficiencies. (productivity/mitigation) - Introduction of crops with high residual biomass would increase SOM which would improve soil structure and drainage. (productivity/adaptation)
Land preparation/ Tillage	- Development of machinery that is able to work under wet soil conditions and does not destroy soil structure. (productivity/adaptation)
Water management	- Better draining of soils. (adaptation/productivity)
Nutrient management	- Use of organic fertilizers may improve soil structure and reduce the use of inorganic (and energy-demanding) fertilizers. (mitigation) - Use of precision application of fertiliser may further improve efficiencies and contribute to mitigation via lower application rates and lower GHG emission intensities. (productivity/mitigation)
Crop protection	- More pest and disease resistant varieties would enable to use less crop protection agents. (adaptation/mitigation) - Decision support tools to increase efficacy of crop protection measures. (adaptation/mitigation)
Harvest	- Development of machinery that is able to work under wet soil conditions and does not destroy the soil structure. (adaptation)

For consumption potato the two most important weather extremes are: 1) a wet start of the season delays planting which reduces yield, and 2) a wet end of the season that inhibits harvesting operations. Climate change scenarios indicated either no change or increased frequency of the extremes. However, statements on changes in frequency are uncertain, due to lack of long (> 30 years) historical weather data and due to uncertainty in climate change projections in terms of rainfall. In climate change scenarios, the uncertainty in rainfall projections is much larger than the uncertainty in temperature projections. Table 3.6 shows CSA options for management operations in potato production in Flevoland.

3.4 Barriers and strategies to implement CSA options

The expected increase in more extreme rainfall and wetter soils may need to be addressed with local water boards. These institutions are responsible for water management of the polder Flevoland and thus have a big stake in the overall water policy including the discharge of water from polders. Discussion between the agricultural sector and water boards can be sometimes problematic because water boards also have to serve other societal objectives, for example, related to nature conservation and fresh water supply for drinking water companies. A dialogue among the relevant stakeholders on how the various interests can also be served in the future is a logical starting point.

Modification of the machine park that is better prepared to operate well under wetter soil conditions involves high costs. Changes in the type of machinery can follow normal depreciation and replacement periods of machinery considering the time scale at which climate change impacts will manifest. Hence, extra financial mechanisms may be required to absorb these costs.

Research may be needed to identify possible trade-offs among CSA attributes of some options. For example, changes in the type of mechanization may serve adaptation of potato cultivation to changing climate conditions but also may result in increased fuel use and GHG emissions. Such considerations can be made explicit by research potentially resulting in better informed decisions, which may differ depending on the local context and priorities.

4. Ethiopia–Rift valley

4.1 General introduction

The area between Awassa and Shashemene in the Rift valley of Ethiopia has been a traditional potato growing area providing fresh potatoes for the Addis Ababa market. The total potato area in Ethiopia is estimated to vary between 160,000 and 250,000 ha but the total potato area in this specific region is unknown.

Average rainfall is on average about 1,000 mm per year with a small rainy season (Belg) in March-April and a long rainy season (Meher) from June to September. The main potato growing season is during the long rainy season as irrigation is not (yet) common. Since elevation differs across the area the region comprises of two agro-ecological zones (MoWR, 2007):

(i) Tepid to Cool Humid Highland Mountains with altitudes ranging from 1,760 to 3,690 m and mean annual temperatures from 16°C in the highlands to 22°C in the lowlands. The mean annual rainfall is 900-2,000 mm. The topography is hilly to mountainous with most areas having slopes of 8-15% although slopes are generally steeper (>15%) along the eastern boundary gentler in Arsi (5-8%).

(ii) Tepid To Cool Sub-moist Mid-highlands with altitudes ranging from 1,625 to 2,300 m and mean annual rainfall of 1,000-1,300 mm. Mean annual temperatures are 16-21 °C. The landscape of the area is one of undulating plains (slopes 0-5%) with occasional dissected hills (slopes 8-15%). The main soils are Luvisols in the north, Leptosols on the hills, Vertisols to the west of Lake Awasa and Andosols and Arenosols in the west.

Conway and Schipper (2011) indicate that rainfall dependent activities/sectors should consider at the very least recent variability (last 20–30 years) as a guide to planning and management and in some cases, where long-term decisions are involved (such as for water infrastructure), they need to consider greater range of variability. For potato production up to 2020 the recent rainfall variability is a good indicator of what to expect, but continued warming may have consequences for evaporative demand. High temperature peaks may increase heat stress but also induce secondary growth, and changes patterns in pest and diseases.

4.2 Assessment of current potato systems in the Rift Valley

Current potato yields in the Rift Valley are low and vary between 8 and 10 t ha^{-1} because of poor management, low input use and inferior plant material. Tentative yield estimates suggest potential potato yields exceeding 60 t ha^{-1} in the main rainy season (Haverkort *et al.*, 2012). This implies that yields of about 45 t ha^{-1} are attainable assuming that 75% of the potential yield level is feasible in practice (Cassman *et al.*, 2003). At this level farm yields generally reach a ceiling because i) farm management is never completely perfect and ii) of the diminishing marginal returns of inputs at higher yield levels. Anyway, attainable yields of 45 t ha^{-1} imply a yield gap with current yields of more than 75%, which can be bridged by good management including the use of good seeds, sufficient fertilizers and adequate crop protection agents (Haverkort *et al.*, 2012).

Most potatoes are grown by smallholders with small land holdings (1-2 ha). Potatoes are considered a fresh vegetable and most are produced for consumers in Addis Ababa. Potatoes are grown in combination with maize, wheat, barley, teff and vegetables depending on the altitude of the production area.

Table 4.1. Characteristics of current potato management in the Rift Valley, Ethiopia (Haverkort et al., 2012).

Management operation	Current status
Variety selection	Jalena, Gudena, Netje and Shashme
Rotation	Barley, wheat, maize, teff and hot chili (depending on altitude)
Land preparation/Tillage/ planting	By oxen, often little tilling of beds
Water management	Rainfed
Nutrient management	DAP and some urea are applied (total about 100 kg ha^{-1}, equalling about 22 kg N ha^{-1})
Crop protection	Late blight fungicides (mancozeb, metalaxyl) applied, but timelines of application is poor, and resistance of some late blight pathogens
Harvest	Haulms are 'killed' by manually cutting of the stems; the cut stems remain on top of the hills. The potatoes are lifted with oxen and then -manually collected about two weeks after cutting.

In Table 4.2 current potato management practices in the Ethiopian Rift Valley are assessed with respect to the attributes of climate smart agricultural practices, i.e. their contribution to productivity, adaptation and mitigation.

Table 4.2. Assessment of current potato management in the Rift Valley of Ethiopia with respect to productivity, adaptation and mitigation.

Major management	Attribute of Climate Smart Agriculture		
operation	Productivity	Adaptation	Mitigation
Variety selection	Production potential is uncertain, but maybe more important is the quality of plant material, which is very low.	Current varieties are able to produce - though low- but face many stresses due to diseases, drought, and heat stress	Potato contributes little carbon biomass to the system as most is harvested.
Rotation	Rotation frequency of potato is unknown.	Potato is a major cash crop in current rotations.	Most crop residues of non-potato crops are harvested for feed purposes. Hence, little carbon is added by rotation crops.
Land preparation/ Tillage	Tillage is shallow while potato hills are poorly constructed reducing yields.		Tillage is shallow and will therefore impact less on SOM decomposition than mechanised tillage.
Water management	Rainfall in the main rainy season does not limit production.		
Nutrient management	Low fertilizer use, while availability and access to fertilizers is sub-optimal. Balanced fertilizer recommendations are lacking.	Inappropriate nutrient management increases crop vulnerability to environmental stress.	Low use of fertilizers implies a limited impact on GHG emissions associated with production and use of fertilizers.

Major management operation	Attribute of Climate Smart Agriculture		
	Productivity	Adaptation	Mitigation
Crop protection	Resistance of late blight is a problem in some areas. Other biological stress unknown. Low availability of and access to crop protection agents. Limited farmer knowledge on pesticide use.	Inappropriate crop protection makes the crop vulnerable to biotic stresses.	Low use of crop protection agents implies a limited impact on GHG emissions associated with production and use of crop protection agents.
Harvest	With oxen followed by manual collecting. Losses are unknown compared to mechanical harvesting		No use of fossil energy, thus low carbon footprint

4.3 Identification of CSA options

Current potato yields are still very low and allow much scope for improvement of potato management in the Rift Valley. Therefore, it is important to identify CSA options especially in the context of productivity increase and closing the current yield gap.

Kassie *et al.* (2013) investigated the potential impacts of climate change on rainfed agriculture in the Central Rift Valley of Ethiopia. Their projected changes in rainfall and temperature were based on eight combinations of four general circulation models (GCMs) and two IPCC SRES emission scenarios, A2 (high emission) and B1 (low emission). Projections from GCMs suggest that future annual rainfall will change by +10 to –40% by 2080. Rainfall will increase during November–December (outside the growing season), but will decline during the growing seasons. Also, the length of the growing season is expected to be reduced by 12–35%. The annual mean temperature is expected to increase in the range of 1.4–4.1 °C by 2080. Conway and Schipper (2011) indicate that current variability in rainfall is a good indication for the period up to 2020. Kassie *et al.* (2013) argue that further improvements in downscaling of GCMs are needed to assess changes in the frequency of weather extremes (heat, drought periods). Table 4.3 shows CSA options for management operations in potato production in the Rift Valley of Ethiopia.

Table 4.3. Different CSA options for the various management operations in potato production in the Rift Valley of Ethiopia. Between brackets the major CSA attribute(s) addressed by the option.

Management operation:	Options:
Variety selection	- Improve the quality of current plant material. (productivity) - Development of potato varieties with higher production potentials than current varieties. (productivity) - Development of varieties more tolerant under warm conditions and adjusted to (expected) shorter growing seasons. (adaptation)
Rotation	- Alternative animal feed sources so that farmers can retain crop residues of non-potato crops in the field. (mitigation) - Incorporation of crops with high residual biomass, which potentially enriches SOM and increases resource use efficiencies. (productivity/mitigation)
Land preparation/ Tillage	- Machinery for better land preparation and tilling. (productivity)
Water management	- Irrigation will increase yields and allows production during other periods of the year with less risks for late blight (productivity/adaptation)
Nutrient management	- Development of fertilizer recommendations. (productivity/adaptation) - Training of farmers in better and more balanced fertilizer use. (productivity/adaptation)
Crop protection	- Better training of farmers in the use of pesticides. (productivity/adaptation/mitigation) - More pest and disease resistant varieties would enable to use less crop protection agents. (productivity/adaptation)

Compared to the Sandveld and Flevoland case much more options address the productivity attribute of CSA in the Rift Valley. This has everything to do with low and under-developed potato sector in the Rift Valley. Considering the current low productivity and large yield gap options that address the productivity attribute of CSA increase could potentially contribute to improved income and livelihoods of local producers.

If irrigation water is available climate conditions (i.e. temperature) in large parts of the Rift valley allow to growth potatoes year-round. Development of irrigated production would also be an appropriate adaptation strategy for the expected drier conditions during the main wet season. At the same time, irrigation would allow producing potatoes in periods with less disease pressure, which could give a boost to potato yields.

4.4 Barriers and strategies to implement CSA options

The introduction of improved varieties and better quality (healthy) plant material is an important starting point to lift current low productivity. Current inadequate seed production systems need to be backed up by certification and seed laws. Breeding rights are often not respected in developing countries including Ethiopia, reducing incentives to breeders to create new adapted and resistant high yielding varieties to local conditions (Lutaladio *et al.*, 2009). The public sector needs to provide the incentives to breeders and enforcement of breeding rights so that healthy seed production systems can be developed.

In general, potato producers in the Rift valley face a large information and knowledge gap (Haverkort *et al.*, 2012). This comes to the fore, for example, in the absence of location-specific fertilizer recommendations and inappropriate use of crop protection agents. Improvement of practical knowledge of farmers through applied research and extension methods is needed to upgrade current low standards.

Two major barriers beyond the local level are the availability of and access to inputs for the production of potatoes. The poor availability of fertilizers and crop protection agents (both in terms of quantities and types) are a constraint for Ethiopian smallholders (Van Putten *et al.*, 2012). Current supply of agricultural inputs, despite recent privatization processes, is still largely controlled by the Ethiopian Government owned and liaised enterprises (such as farmer unions). In addition, various types of fertilizers (such as potassium) and pesticides are not available or allowed to be used in Ethiopia unless special permissions are provided by the authorities such as for large scale flower farms producing for the export. Further privatization of the input supply sector and development of pesticide admission policies could improve the availability of agricultural inputs for smallholder potato farmers.

The other barrier, accessibility, relates to the fact that many CSA options are not within the financial reach of smallholders. Improved seeds, fertilizers, pesticides, let alone mechanization, are costly inputs of which the expenses are made at the beginning of the growing season when farmers lack cash. Therefore, strengthening of the agro-finance sector is required enabling the provision of credit to smallholders for buying inputs. Probably, lifting this barrier will also require acceleration of the process of land reform, certification and land ownership so that i) land can be used as collateral, ii) farmers are stimulated to invest to maintain and increase the production potential of their land, and iii) the related processes of farm expansion and exiting from agriculture are stimulated to arrive at a more viable farm structure.

5. Discussion and conclusions

Except for the general guidelines for sustainable potato production in developing countries (Lutalido *et al.*, 2009) there are no good agricultural practices defined for consumption potatoes in each of the case study areas. Only the Biodiversity Best practice Initiative (BBI) in Sandveld (Section 2.3) provides a set of guidelines for good agricultural practices from a biodiversity point of view. Guidelines for good agricultural practices need to be location and context specific as the BBI guidelines demonstrate (Table 2.5). Some of the guidelines go beyond the management at field level but also address farm and landscape levels. Especially in the Sandveld case, which is endangered by over-exploitation of groundwater resources and conversion of natural habitat by agriculture, the need to address the landscape level in GAP is evident. Results of the CSA/GAP framework applied in the cases further support the conclusion that location and context specific GAP guidelines need to be formulated with a broad spatial and temporal focus allowing to account for impacts of climate change.

In general, global potato productivity is expected to benefit more from an increase in atmospheric CO_2 concentrations than productivity is reduced due to anticipated changes in climate conditions such as temperature and rainfall (Haverkort & Verhagen, 2008; Wolf *et al.*, 2011). The effect of climate change on the frequency and severity of weather extremes affecting potato productivity remains highly uncertain. Some plausible, but hard to verify effects associated with climate change such as changes in abiotic pressures are also uncertain. Despite these uncertainties, the anticipated impacts of climate change in the case study areas show a very divers picture: A decline in ground water resources (South Africa), shorter and drier growing seasons (Ethiopia) and increased frequency of wet soil conditions (The Netherlands) are among the most important effects associated with the expected change in climate in each of the case study areas. Local potato producers will face these impacts and will have to adapt their current management practices to these new conditions. Acknowledging such potential climate impacts adds a dimension to GAP or reiterates the importance of sustainability aspects already addressed in existing GAP. For example, the water management guidelines in Sandveld's BBI to use water more efficiently are based on biodiversity concerns. The importance of these water management guidelines is further stressed by the potential impacts of climate change in Sandveld, i.e. the expected decline in ground water resources due to reduced recharge of groundwater reserves.

Based on the smallest yield gap of the three cases, potato production in Flevoland is most developed and is least affected by expected climate change. More rainfall during planting and harvesting may require adaptation of machinery to be better prepared for wetter soil conditions. However, changes in mechanization fit in the usual period of depreciation and renewal of machinery considering the time horizon of expected climate impacts. An expected shorter and drier growing season may require adaptations of the current system in the Rift Valley, for example, through the introduction of irrigation. Such adaptation would allow a fundamental change in the potato systems as it allows producing potatoes during the dry season. If water resources are available and used with care such a transformation of the potato system potentially could create synergy: Lower biotic pressure in the dry season could result in higher potato yields. In terms of development, Sandveld takes an intermediate position but its current dependency on limited ground water resources and anticipated decline in ground water resources probably poses the largest adaptation challenge of the three cases.

The Rift Valley case shows that in the least developed case (largest yield gap) priorities primarily are related to the productivity attribute of CSA. Closing this yield gap will inevitable result in trade-offs among the attributes of CSA. Increasing potato productivity in the Rift Valley will require considerably more inputs, particularly (nitrogen) fertilizers, pesticides and mechanization. Inputs that all require directly or indirectly fossil energy and the higher input use will be, therefore, accompanied by higher GHG emissions per unit of land and initially also per unit product. The challenge will be to increase yield levels such that GHG emissions per unit of produce are more favorable compared to the current situation. The other case studies also include such trade-offs but not as prominent as in the Rift Valley. Research may be needed to identify possible trade-offs among CSA attributes of options. For example, changes in the type of mechanization may serve adaptation of potato cultivation in Flevoland to expected wetter soil conditions during planting and harvest. However, this option may also result in increased fuel use and GHG emissions. Such considerations can be made explicit by research resulting in better informed decisions, which may differ depending on the local context and priorities.

None of the case studies shows immediate and large potentials to address the mitigation agenda of CSA. This is largely related to the biological characteristics of the potato. About 80% of the biomass is harvested while for most cereals this percentage is less than 50%. The potentials for conservation tillage as mitigation option in potato are limited: Potato crop yields are sensitive to proper soil preparation (Riley & Ekeberg, 1998), crop residues of the previous year hamper planting, while harvesting of the belowground potato biomass requires anyway disturbance of the soil. In an indirect way potato management can serve mitigation goals by more efficient use of fertilizers, irrigation water (energy use), pesticides and less field traffic. Also options that go beyond the spatial and temporal system boundaries of potato cultivation can contribute to mitigation goals, for example, through the inclusion of crops with a high residual carbon biomass in potato rotations.

In contrast with trade-offs among CSA attributes such productivity increase and mitigation some options present synergies. For example, potatoes have high fertilizer requirements but low utilization efficiency; Using fertigation with drip irrigation instead of sprinkler irrigation as in the Sandveld case has potentially benefits in terms of increased productivity, decreased water use (adaptation) and reduced nitrogen input (mitigation). It is important to grasp these opportunities in an early stage (low hanging fruit, or no-regret options), which may require high initial investments.

The three case studies Sandveld in South Africa, Flevoland in the Netherlands and the Rift Valley in Ethiopia differ in socio-economic development conditions, which explain largely the differences in institutional and financial barriers to make CSA options reality. The strong dependency on ground water resources in Sandveld will require collaboration between the agricultural sector, local water authorities and nature conservation organizations. In the Rift Valley Programmes to upgrade the skills and expertise of potato producers need to be matched by government initiatives to privatize the agriculture input supply chain, reform land use policies and facilitate financial institutions to invest more in agriculture. In general, CSA strategies should be integral part of the development agenda in developing countries such as Ethiopia. Last but not least the case studies show that an R&D agenda for CSA should go beyond the common call for crop species or livestock breeds adapted to projected climate conditions (e.g. Wollenberg *et al.*, 2012). Equally important for such an agenda is the identification of location-specific technical options and institutional and financial barriers to facilitate adoption of such options. Such options are not necessarily innovative from a global perspective as they often will have shown their suitability in other regions, and they should be the result of location-specific R&D agendas aimed at efficiency and productivity improvements as part of climate smart agriculture. The main contribution of CSA and the tested framework to GAP and development in general is that long-term thinking on productivity, adaptation and mitigation goals becomes an explicit and integrated component of sustainable intensification of agriculture.

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Appendix I.
Climate factors and impact on potato production

Climate condition	Description	Period	Impact
Early and prolonged rainfall	Period of 21 days of more than 0.5 mm rainfall on 75% of the days	October-April	Ploughing and field preparation
Heavy rainfall	Daily precipitation of at least 45 mm or at least 60 mm in 3 days	May-September	Limits field accessibility and induces tuber decay
Heat wave	At least 3 days with more than 30°C in a period of at least 5 days	July-September	Inducing secondary growth
Hot and wet	At least 14 consecutive days with a maximum temperature above 20°C and for 50% of the days at least 0.5 mm rain	July-September	Inducing diseases, especially *Erwinia*
Extreme heat	Period of 2 days with temperatures of 40°C or higher	July-September	Death of canopy due to high transpiration and burning
Late and prolonged rainfall	Period of 21 days of more than 0.5 mm rainfall on 75% of the days	August-October	Not able to harvest and damage to tubers
Frost	Period of at least 2 days with daily maximum temperature less than -2 °C	April-May	Killing seed potatoes in spring
Warm winter	Period of at least 14 days with a maximum temperature above 10 °C	December-March	Rotting of tubers and early sprouting