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Alterra Report 2352
ISSN 1566-7197

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WAGENINGEN UR
For quality of life

Ministry of Economic Affairs, Agriculture and Innovation

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This report was prepared as part of BO Project-10-011-012 for the Ministry of Economic Affairs, Agriculture and Innovation.
The contact persons for this project were Ir. P. Vaandrager, Drs. M.K. Boshuizen and Ing. S.R.R. Croqué.

Photo cover top: Greenhouse vegetable in Africa (Africa924/www.Shutterstock.com)
Photo cover bottom: Spreading fertiliser on irrigated lands on a small scale farming operation in the Drakensberg foothills, Kwazulu-Natal. Underberg, South Africa (WOLF AVNI/www.Shutterstock.com)

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1 Alterra
2 Plant Research International

Alterra Report 2352

Alterra Wageningen UR
Wageningen, 2012

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Abstract

Simone Verzandvoort, Christy van Beek, Sjaak Conijn, Jochen Froebrich, Herco Jansen, Gert-Jan Noij, Koen Roest, Jan Vreke and Madeleine van Mansfeld, 2012. *Sustainable agricultural intensification in Sub-Saharan Africa*; *Design of an assessment tool.* Wageningen, Alterra, Alterra Report 2352. 62 pp.; 23 fig.; 12 tab.; 60 ref.

Abstract The demand for agricultural products (food, feed, fibre, and biomass for other purposes) produced in Sub-Saharan Africa (SSA) will increase for the coming decades. In addition, the global climate change will largely impact on the agricultural sector in Sub-Saharan Africa. Major challenges for the agricultural sector in SSA are that agricultural production systems depend on resources that are for a large part non-renewable, and that the current agricultural practices in SSA are major contributors to environmental degradation. The Government of the Netherlands addresses food security and sustainable agricultural production in Sub-Saharan Africa. In order to support this process, the Ministry of EL&I has asked for 'a concept' to evaluate options for agricultural developments, which are aimed at increasing productivity and improving livelihoods, whilst safeguarding or improving ecosystems. This report presents analyses of yield gaps in Africa, nutrient use and requirements for crop land, and of fresh water production and crop evapotranspiration. The yield gap analysis was based on spatial databases and simulations of potential (irrigated) and water-limited maize yields with a crop growth model. The yield gap in Africa varies largely, ranging from 5 to 60%. The potential improvement for land productivity is large (up to 7 times the actual production levels), even without the help of irrigation. The analysis of nutrient use and requirements for cropland in Africa showed that closing the yield gap requires a higher N and P availability to crops. The analysis of the fresh water production per capita and evapotranspiration from cropland revealed that changes in cropland management, e.g. targeted to increase crop yields and evapotranspiration, can have a dramatic effect on fresh water production and may call for cropping systems that are efficient in water use. From a water use perspective the intensification of agriculture should be assessed at the regional (river basin) level, taking account of the spatial position of the country with respect to water-stressed basins. In the allocation of water resources, priority should be given to the areas where the highest return on water resources can be achieved in terms of types of water use or production systems. The report presents a tool to presented to evaluate strategic plans for the development of agriculture to increase food security in Sub-Saharan Africa. The tool can assist in identifying and evaluating alternative strategies for agricultural intensification in a participatory process. Apart from the Ministry of EL&I, other potential actors and stakeholders in such a process are the Dutch embassies in the pilot countries, governmental planning agencies, the private sector (local and foreign investors), NGOs (local and international NGOs), and knowledge institutes.

Keywords: Agricultural production, Sub-Saharan Africa, yield gap, water productivity, assessment tool.

The report goes with the outline of the Sustainability Assessment Tool in the Excel spreadsheet 'sustain-v05-final.xlsx' (MS 2010). A copy of the software can be requested from simone.verzandvoort@wur.nl or jan.vreke@wur.nl.

ISSN 1566-7197

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Alterra Report 2352
Wageningen, August 2012

Contents

1 Summary

Challenges for agricultural production in Sub-Saharan Africa
The demand for agricultural products (food, feed, fibre and biomass for other purposes) produced in Sub-Saharan Africa (SSA) will increase for the coming decades. In addition, the global climate change will largely impact on the agricultural sector in Sub-Saharan Africa. Particularly smallholders have limited capacity to cope with these trends. Food security in Sub-Saharan Africa is not only at stake because of shortfalls in local production, but also because of increased commodity prices. Major challenges for the agricultural sector in SSA are that agricultural production systems depend on resources that are for a large part non-renewable, and the current agricultural practices in SSA are major contributors to environmental degradation.

Many observers agree that an intensification of agricultural production in Sub-Saharan Africa can only be achieved in a sustainable way by considering trade-offs between food security, economic benefits, socio-cultural benefits and environmental effects (use of natural resources, emissions and biodiversity). However, global drivers of change also interact strongly with local circumstances (e.g. soil fertility, water availability or socio-economic conditions), resulting in complex interactions. In such situations, the catch-cry 'we need to produce more with less' should rather be interpreted as 'producing more with more, but smarter', which is often more productive and sustainable.

The Dutch government's approach to agricultural development in Sub-Saharan Africa
As part of the preparations for the Rio+20 summit, the Government of the Netherlands had designed several trajectories to address food security and sustainable agricultural production in Sub-Saharan Africa. In order to support this process, the Ministry of EL&I has asked for 'a concept' to evaluate options for agricultural developments, which are aimed at increasing productivity and improving livelihoods, whilst safeguarding or improving ecosystems.

A tool for assessing sustainable agricultural intensification in Sub-Saharan Africa
The policy support (BOCI) project 'Sustainable Agricultural Intensification without Degradation' (BO-10-011-012) developed a tool to evaluate strategic plans for the development of agriculture to increase food security in Sub-Saharan Africa. The target group of the tool includes policy makers within the Ministry of EL&I and Foreign Affairs involved in the activities of the Task Team on Food Security. The tool can assist in identifying and evaluating alternative strategies for agricultural intensification in a participatory process. Other actors and stakeholders in such a process are the Dutch embassies in the pilot countries, governmental planning agencies, the private sector (local and foreign investors), NGOs (local and international NGOs), and knowledge institutes.

The proposed tool can be used for:
1. *Supporting the development strategies and policy decisions*
2. *Monitoring and evaluation*
3. *Communication and discussion with stakeholders*

Yield gaps in Africa, land use trends, water use and nutrient use
The development of the tool was accompanied by an analysis of yield gaps in Africa based on spatial databases and simulations of potential (irrigated) and water-limited maize yields with a crop growth model. The yield gap in Africa, but also in most of the selected target countries by the Dutch Ministries of EL&I and

FA varies largely, ranging from 5 to 60%. The potential improvement for land productivity is large in Africa (up to 7 times the actual production levels) even without the help of irrigation, which again illustrates the large yield gap in Africa. An analysis of land use trends over the period from 2000 to 2007 showed that the production increase was insufficient to substantially reduce the number of undernourished people in Sub-Saharan Africa. An analysis of the fresh water production per capita and evapotranspiration from cropland reveal that changes in cropland management, e.g. targeted to increase crop yields and crop land ET, can have a dramatic effect on fresh water production and may call for cropping systems that are efficient in water use in those situations. Further research is needed to calculate the fresh water production values for watersheds instead of countries, taking into account other available water sources that determine total water availability in a country, such as in- and outflow of streams, groundwater reserves.

A first attempt to consider other sources of available water showed that these differ considerably between countries in Sub-Saharan Africa. Some countries, like Ethiopia and Rwanda, are upstream countries, not depending on inflow from neighbouring countries, while other countries depend for 40 to 60 % on water resources from upstream countries, but (except for Mali) they still have considerable 'internal' water resources. From a water use perspective the intensification of agriculture should be assessed at the regional (river basin) level, taking account of the spatial position of the country with respect to water-stressed basins. In the allocation of water resources, priority should be given to the areas where the highest return on water resources can be achieved in terms of types of water use or production systems.

An analysis of nutrient use and requirements for cropland in Africa showed that closing the yield gap requires a higher N and P availability to crops. In the calculation presented for cereals in the whole of Africa N and P removal with grains increased with a factor of 7 - 9, and this availability of N and P is much larger than the estimated inputs. It is, therefore, not possible to increase the (cereal) productivity in Sub-Saharan Africa and maintain the soil fertility without the use of external nutrient inputs. This conclusion is in line with previous investigations on nutrient balances. In the calculation presented in this report, the total input of organic fertilizers exceeded the total removal, which indicates an overall unsustainable situation, because more organic fertilisers are assumed to be applied than produced on crop land. Currently, research is being done aiming at a more precise estimation of the minimum fertilizer requirements for given yield levels while maintaining soil fertility. In addition, more information is needed on the fraction recoverable manure that can be used at crop lands in Africa.

The report elaborated on the management and allocation of water as a critical production factor for agricultural production. Water productivity was recalled as a useful indicator for the profit aspect of sustainable agricultural intensification for the policy objectives food security (in that case defined as crop water productivity) and income security (in that case defined as economic water productivity). The use of the water productivity indicators in sustainability assessments was illustrated for case studies of land use change in Mozambique and a change of farming systems in Ethiopia.

Set-up of the tool and guidelines for use

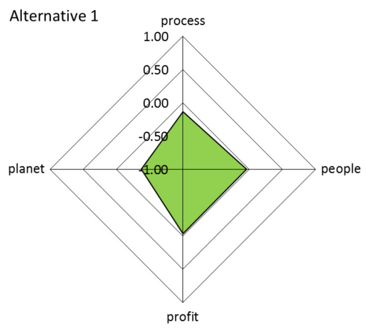
The assessment tool developed in this project can be used to support all phases in sustainable agricultural development: creation of awareness of the effects and effectiveness of agricultural intensification, the setting of objectives for the agricultural intensification, the development of strategies to realise these objectives, the implementation of selected strategies and the phase of monitoring and evaluation. The tool may help to identify priority ‘bright spots’ for investment in agricultural development (i.e. with good scores on all four aspects of sustainability). The framework is capable to incorporate different types of trade-offs and spatial and temporal scales. The proposed tool can easily be used to communicate results of the sustainability assessment to stakeholders due to its simple set-up and visualisation of results.

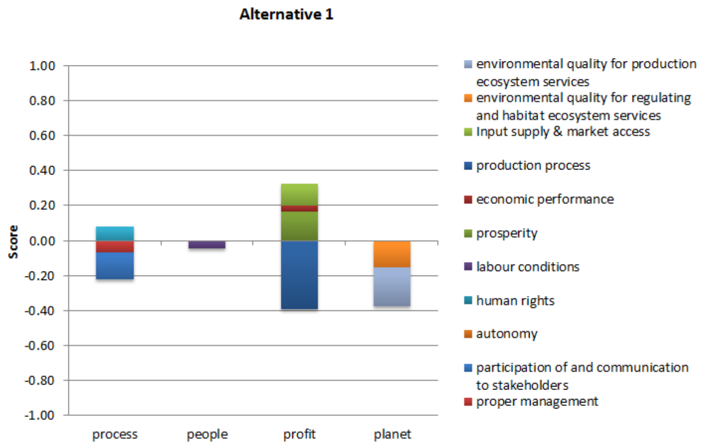
The tool is based on a multi-level instrument for MCA developed to test the sustainability of Metropolitan Food Clusters by Vreke (2010). It uses multi-criteria analysis (MCA), and is organised at four hierarchical levels: (1) final evaluation of the strategy for sustainable intensification, (2) aspects, which are the four aspects of sustainability: profit/prosperity, people, planet and process, (3) criteria within each aspect, and at one level lower: attributes, describing the accountability of actors for processes and external foot prints (ecological and social), (4) and indicators, used to express effects of agricultural intensification on the actors involved and the society in tangible scores.

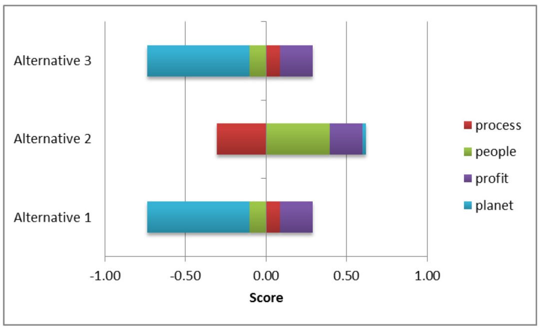
The criteria, attributes and indicators were partly adapted to connect agricultural production and ecosystem services to sustainability and ecological foot prints following Noij et al. (in prep.).

Steps in the application of the tool include:
1. *A problem analysis*
2. *The setting of sustainable target values to indicators*
3. *Describing the situation of indicators for the alternative(s)*
4. *The scoring of indicators*
5. *The assignment of weights to various levels of sustainability measures, and*
6. *A final assessment and negotiation of sustainability options*

The problem analysis consists of an identification of relevant sustainability issues in the area concerned, the selection of spatial and temporal scales for the sustainability assessment and the selection of relevant criteria, attributes and indicators. The approach taken in the presented tool is that the final selection of indicators, and also the weights assigned to these (step 5), determine the score of a strategy for sustainable intensification, and that this score is influenced by the user's perception of sustainable development.







The scoring of indicators (step 4) requires the definition of dose-response relations between measures (i.e. agricultural interventions) or inputs and effects on the indicators (outputs). This may range from expert judgement type qualitative evaluation in terms of +/- to highly sophisticated deterministic dynamic modelling. Steps 5 and 6 require the analysis of trade-offs, being situations that involve losing one quality or aspect of something in return for gaining another quality or aspect. This is required to prevent that a stakeholder's or sector's interest creates a biased view if trade-offs between the aspects of sustainable development are not detected in the perspective of that stakeholder or sector.

The final assessment of alternatives for sustainable agricultural intensification involves aggregating scores on successively indicators, attributes, criteria and aspects using a multi-criteria analysis. The results can be visualised in different ways (see the examples below), and used to discuss and negotiate the alternatives with stakeholders.

Example application of the tool

The use of the tool was demonstrated for an agricultural system with low input and low output in Ethiopia, showing the effects of different nutrient management strategies on the sustainability aspects profit and planet. The score on profit was higher for the crop-oriented smallholder farming system, because the value to cost ratio (VCR) for fertiliser was more close to the sustainable target value. Revenues were similar for both systems, and therefore economic performance had a zero score in both cases. Both systems had negative scores on the planet aspect due to negative nutrient balances.

Recommendations

The authors strongly recommend to gain a first experience with the developed indicator framework and tool in a context (strategy, program or project) where options for agricultural development are currently being identified and selected together with stakeholders as part of a strategy for sustainable agricultural intensification.

Challenges for further developing the tool include the addition of forward control mechanisms like upstream/ downstream feedback interactions, for example with regard to the use of water for agricultural production. The water productivity was proposed as a useful indicator to describe such spatial interactions. Another challenge is to adapt the tool to take account of changing biophysical or socio-economic exogenous drivers of agricultural production, like climate change and increased climate variability (i.e. to enable 'climate-smart agriculture') or population growth.

The development of the tool revealed that quantifying sustainable target values of criteria, attributes or indicators is not a trivial and straightforward issue, since these depend on site-specific or regional settings. Target values of indicators can be based on policy targets, ecological thresholds, general trends and/or expert knowledge. Furthermore more understanding is recommendable on when to study enterprises or production systems individually, and when to consider aggregated agro-ecological land use types.

Embedding the approach of assessing sustainability into a wider framework to enable agricultural development and green growth will be a critical step to gain wider acceptance of sustainability assessments. More involvement of actual enterprises in the case studies is critical to consider the economic requirements for innovative agribusiness ideas from the beginning, and to tailor the further development of assessment tools to such practical needs.

2 Rationale

Since the food crisis in 2008, sustainable food supply and nutrition have regained interest from the global policy arena. A series of influential reports has signalled trends of increasing populations, urbanization and changes in consumption patterns, causing an increasing and changing (e.g. more proteins) demand for agricultural products (food, feed, fibre and biomass for other purposes) for the coming decades (IAC, 2004; IAASTD, 2009; FAO, 2009; IFPRI, 2010; WorldWatch Institute, 2011a,b; AGRA, the Foresight Report, 2011; Von Grebmer et al., 2011). In addition, the global climate change will largely impact on the agricultural sector in Sub-Saharan Africa. Particularly smallholders have limited capacity to cope with these trends. Food security is not only at stake because of shortfalls in local production, but also because of increased commodity prices (Thornton et al., 2011).

Most views agree that an increase of agricultural production in Sub-Saharan Africa is mainly to be realized through intensification of agriculture on existing agricultural land. Intensification of agricultural production can only be achieved in a sustainable way by considering trade-offs between food security, economic benefits, socio-cultural benefits and environmental effects (use of natural resources, emissions and biodiversity). This boils down to achieving higher levels of eco-efficiency: to increase the production of agricultural outputs for less input of land, water, nutrients, energy, labour or capital (Keating et al., 2010; De Visser et al., 2010). However, global drivers of change also interact strongly with local circumstances (e.g. soil fertility, water availability or socio-economic conditions), resulting in complex interactions. In such situations, the catch-cry 'we need to produce more with less' should rather be interpreted as 'producing more with more, but smarter', which is often more productive and sustainable (Meinke et al., in prep.).

The above described concerns are particularly challenging Sub-Saharan Africa (SSA), which is exposed to enormous stresses, and which is still depending largely on subsistence agriculture (Meinke et al., in prep.; Breman and Debrah, 2003). Gitau et al. (2009) identify two major challenges for the agricultural sector in SSA: 1. Agricultural production systems depend on resources that are for a large part non-renewable, 2. The current agricultural practices in SSA are major contributors to environmental degradation. Meinke et al. (in prep.) plea for an efficiency increase of the exhaustible production factors (land, water, capital and labour) by substituting and complimenting them with the non-exhaustible production factors knowledge and practical wisdom, which requires access and use of 'knowledge intensive technologies'.

2.1 Policy framework

Food and agriculture are key issues for the themes 'Green Economy' and 'Institutional Frameworks' at the UNCSD 2012 (Rio+20), which is aimed at strengthening coherent food security policy and fostering the implementation of sustainable agriculture. As part of the preparations for the Rio+20 summit, the Government of the Netherlands has designed several trajectories to address food security and sustainable agricultural production in SSA. In one of these trajectories food security is linked to rural development, from the vision that agriculture is the 'engine' for rural development. The Directorate of International Affairs of the Ministry of Economic Affairs, Agriculture and Innovation (EL&I) is committed to take food security a step further. Together with the Ministry of Foreign Affairs a Task Team has been established to foster food security in six pilot countries of SSA.

In order to support this process, the Ministry of EL&I has asked for 'a concept' to evaluate options for agricultural developments, which are aimed at increasing productivity and improving livelihoods, whilst safeguarding or improving ecosystems. It is widely acknowledged that the strategies and technologies needed to achieve sustainable agricultural development in SSA are different from the 'knowledge-embedded' technologies that drove the Green Revolution of the 1960s and 1970s (Park et al., 2010; Meinke et al., in prep.; Pretty et al., 2011). Instead, a sustainable 'Rainbow Revolution' in agriculture, within the diversity of agro-ecological contexts in Sub-Saharan Africa, will require knowledge intensive technologies (Rabbinge, oral comm.; Meinke, 2011). Such a revolution needs to be supported by good policies, good governance, and good cooperation and co-learning between actors in agro-logistical chains and research (e.g. Breman and Debrah, 2003; Ten Pierick and Meeusen, 2004).

2.2 Project objectives

At the request of the Dutch Ministries of EL&I and Foreign Affairs, the policy support (BOCI) project 'Sustainable Agricultural Intensification without Degradation' (BO-10-011-012) aims at developing a tool to evaluate strategic plans for the development of agriculture to increase food security in SSA. The proposed tool should follow the paradigm of 'corporate social responsibility' (CSR), which is becoming an important standard in business and industry (e.g. Lambooy, T., 2011; Ministry of Economic Affairs, Agriculture and Innovation and Ethiopian Ministry of Agriculture, 2010). CSR is a concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis (EC, 2011).

Since the Ministries of EL&I and Foreign Affairs envisage a more important role of the private sector in the development of SSA, the principles of CSR should as much as possible be linked with sustainable agricultural intensification. This enables, as phrased by Eenhoorn (2011), 'a holistic and entrepreneurial approach' to agricultural development.

2.3 Beneficiaries

The target group of the tool includes policy makers within the Ministry of EL&I and Foreign Affairs involved in the activities of the Task Team on Food Security. The tool can assist in identifying and evaluating alternative strategies for agricultural intensification in a participatory process. Other actors and stakeholders in such a process are the Dutch embassies in the pilot countries, governmental planning agencies, the private sector (local and foreign investors), NGOs (local and international NGOs) and knowledge institutes.

The proposed tool can be used for:
1. Support to development strategies and policy decisions
2. Monitoring and evaluation
3. Communication and discussion with stakeholders

2.4 Methodology

The tool is based on an existing instrument for sustainability assessments after Vreke et al. (2010). In the tool the economic, environmental and social aspects of sustainable development are integrated in a consistent way through the use of four sets of indicators that cover the various aspects of sustainability. These sets of indicators were based on existing indicator frameworks for sustainable development, and adjusted and supplemented by various experts from Wageningen UR and policy makers. For this purpose an expert workshop on sustainable intensification in SSA was also organised within the framework of this project[1]. Based on the Terms of Reference for this project, the tool focuses on the soil and water-related indicators.

[1] Workshop Sustainable Agricultural Intensification in Sub-Saharan Africa, organised by Alterra on assignment of EL&I in the framework of BO Project 10-011-012 on May 25th 2011, in Wageningen.

3 Need for agricultural intensification

3.1 Yield gap

The 'Green Revolution' bypassed Africa. Sub-Saharan Africa has currently the lowest land and labour productivity rates in the world, and food production lags behind the already low growth of agriculture in general (De Graaff et al., 2011; Pretty et al., 2011; Breman and Debrah, 2003). The annual increase of cereal yields is not sufficient to keep pace with the population growth.

Section 3.2 presents an assessment of the yields of maize, which is an important cereal for the food security in Sub-Saharan Africa. The yield gap is defined as the difference between the potential yield and the actual yield (Figure 3.1). The available food may still be significantly less than the actual yield as a result of post-harvest losses (Figure 3.1), which are estimated at 30 - 40 % on average for SSA. The low actual yields are not only the result of non-optimum conditions in terms of biophysical conditions and external inputs (especially fertilizers, crop varieties and irrigation), but also of inadequate knowledge and skills ('know ware') and poor (access to) physical and financial infrastructures ('orgware') (Figure 3.1).

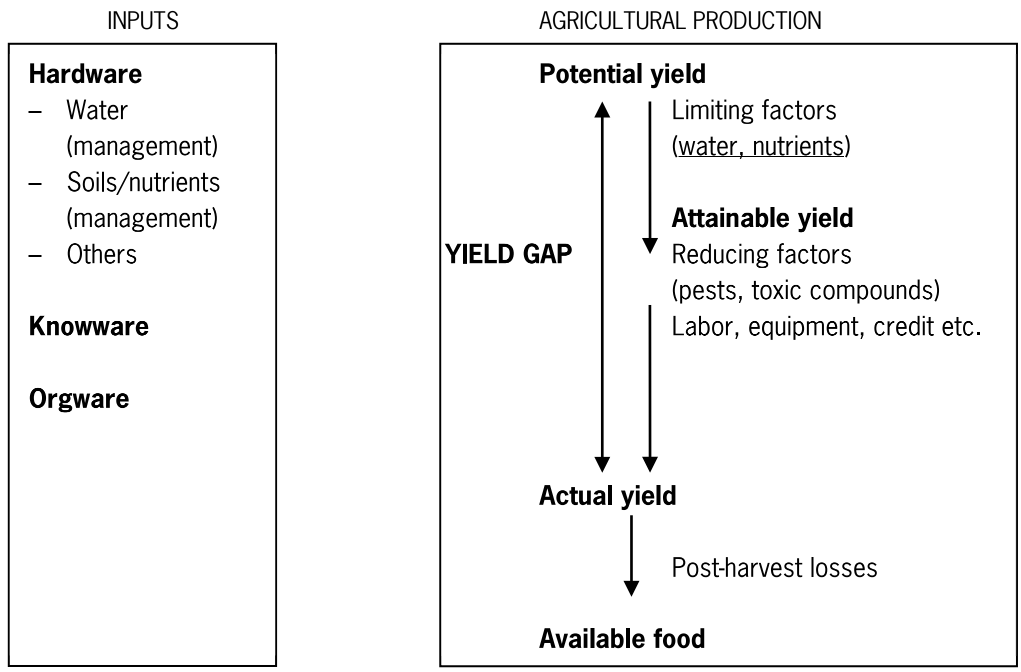


Figure 3.1
Concept of yield gap. Source: Herco Jansen, Alterra.

Many research projects and programs have indicated steps to increase agricultural production (e.g. IAC, 2004; Bindraban et al., 2009; Van Berkum et al., 2011; De Visser et al., 2010; the 'Alliance for a Green Revolution in Africa' project), some of which are cited below:

1. Increase efficient use of external resources.
2. Reduce the depletion of natural resources (water, soil fertility).
3. Precision farming (fine-tune resource use and on-farm management).
4. Reduce post-harvest losses, e.g. through better agro-logistics.
5. Shift to higher value products.
6. Shift to integrated systems re-using water, nutrients, waste and side products.

3.2 Mapping yield gaps in Africa

Using spatial databases a yield gap analysis for maize in Africa has been performed (Conijn et al., 2011). The objective of this analysis was to generate information on the current 'output level' of agricultural production systems in Africa, particularly in the six target countries selected by the Task Force on Food Security.

The actual maize yields were based on Monfreda et al. (2008), while potential (irrigated) and water-limited maize yields were calculated using a crop growth model. By combining a map with irrigated areas (Siebert et al., 2005) with the cropland map of Ramankutty et al. (2008), the fraction cropland equipped for irrigation was determined per grid cell (5 x 5 arc-minutes). The weighted average yield was calculated per grid cell using the simulated potential and water-limited yields for maize. The actual maize yield as percentage of this simulated yield is illustrated in Figure 3.2 (for whole Africa) en in Figure 3.3 to Figure 3.8 for the African countries that were selected as partner countries under profile 1 (B. Knapen; Focusbrief ontwikkelingssamenwerking, 18-02-2011).

It can be concluded that the yield gap in Africa, but also in most of the selected target countries varies largely, ranging from 5 to 60%. Rwanda, Mozambique and Mali have on average a relatively low yield gap, while Benin, Ethiopia and Uganda have relatively large yield gaps (Table 3.1). To analyse the causes of these differences an in-depth analysis of irrigation practices, fertiliser use and crop calendars is required. This example for maize confirms the huge potential for increase of agricultural productivity. It is likely that similar conclusions can be drawn for other crops in Africa (e.g. FAO, 2011).

Table 3.1
Actual maize yield expressed as percentage of simulated (potential) yield (-) for dominant and non-dominant situations per country based on visual inspection of Figure 2a-f.

Target country	Dominant	Non-dominant
Benin	15 - 40	5 - 15
Ethiopia	10 - 30	30 - 80
Mali	5 - 30	
Uganda	10 - 30	30 - 40
Mozambique	5 - 20	0 - 5 20 - 30
Rwanda	0 - 15	

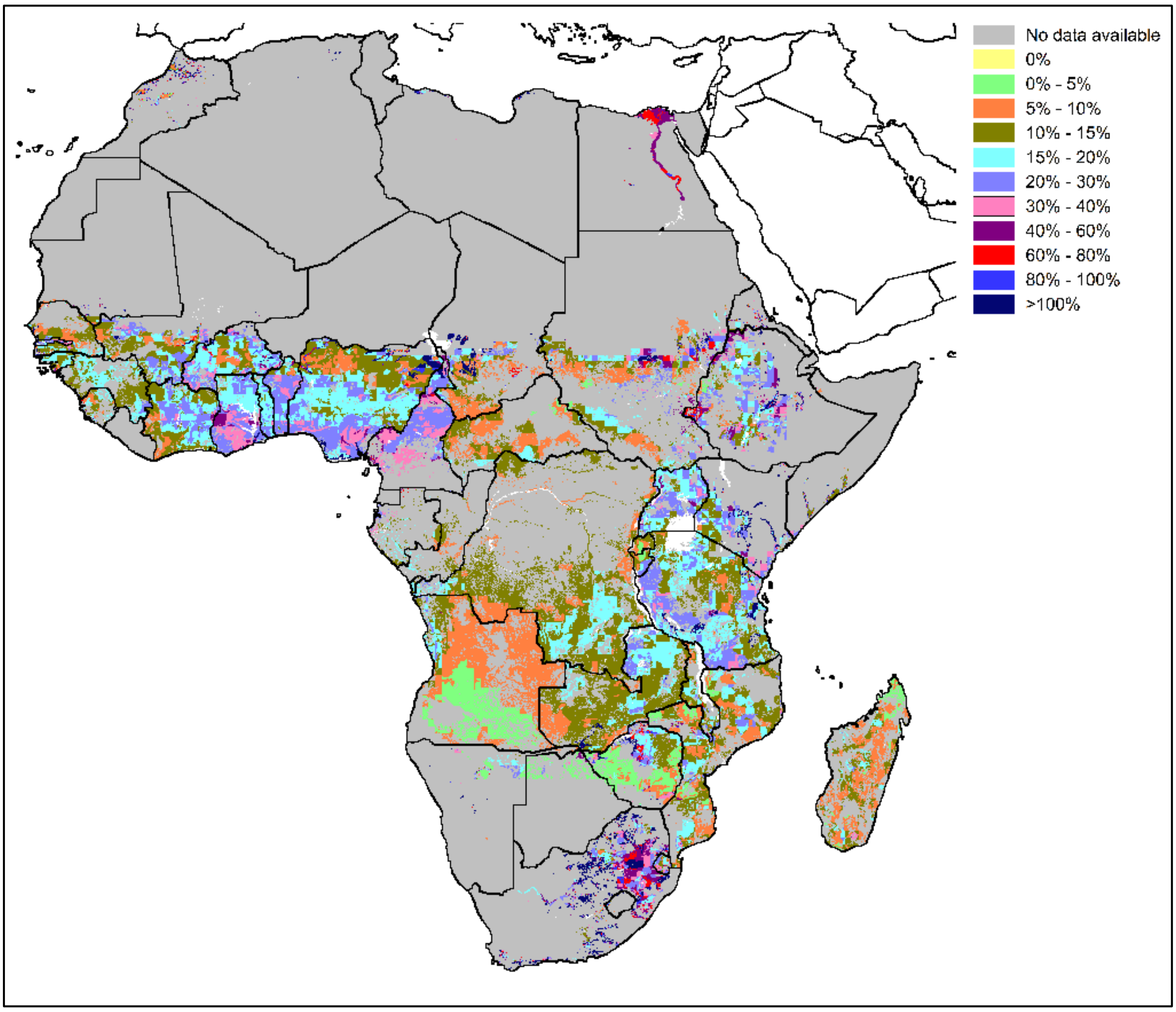


Figure 3.2
Actual maize yield as percentage of potential (irrigated and water-limited) yield in Africa. White areas illustrate sea/oceans and inland waters, grey areas refer to areas without maize cultivation or a zero simulated yield.

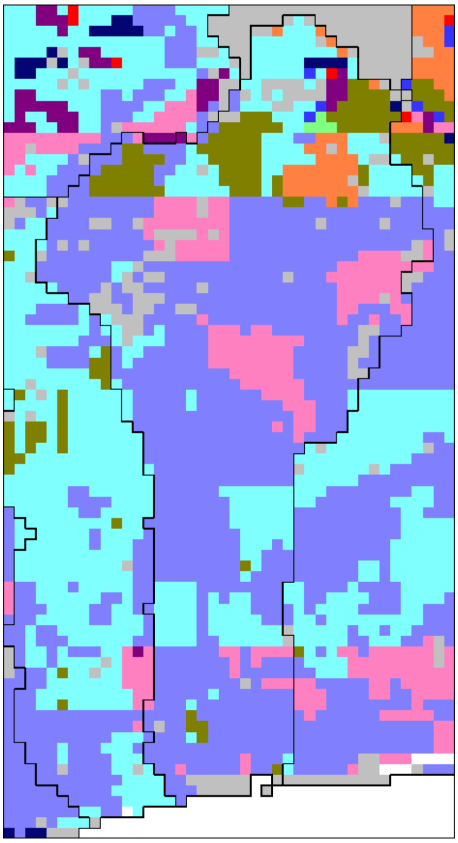


Figure 3.3
Actual maize yield as percentage of calculated potential yield in Benin (enlarged from the map in Figure 1). Legend as in Figure 1.

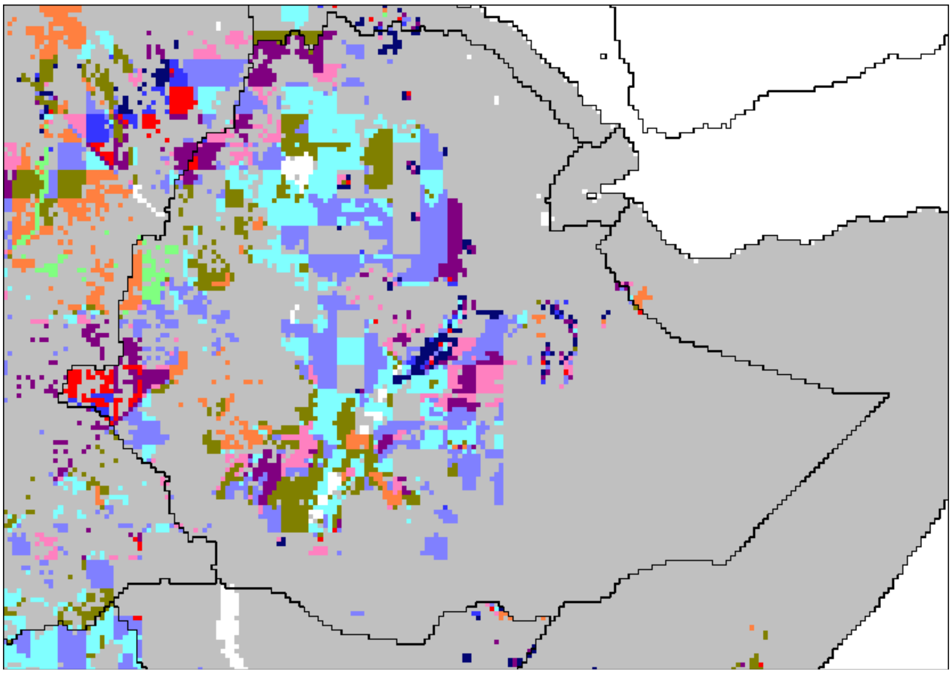


Figure 3.4
Actual maize yield as percentage of calculated potential yield in Ethiopia (enlarged from the map in Figure 1). Legend as in Figure 1.

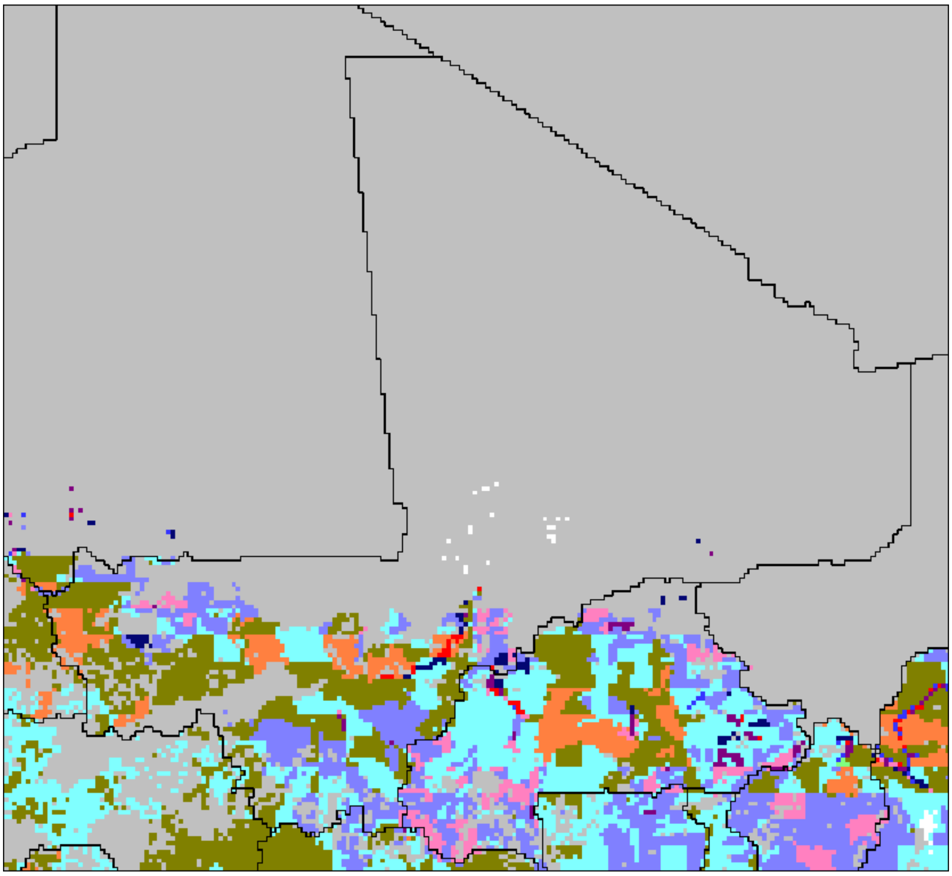


Figure 3.5
Actual maize yield as percentage of calculated potential yield in Mali (enlarged from the map in Figure 1). Legend as in Figure 1.

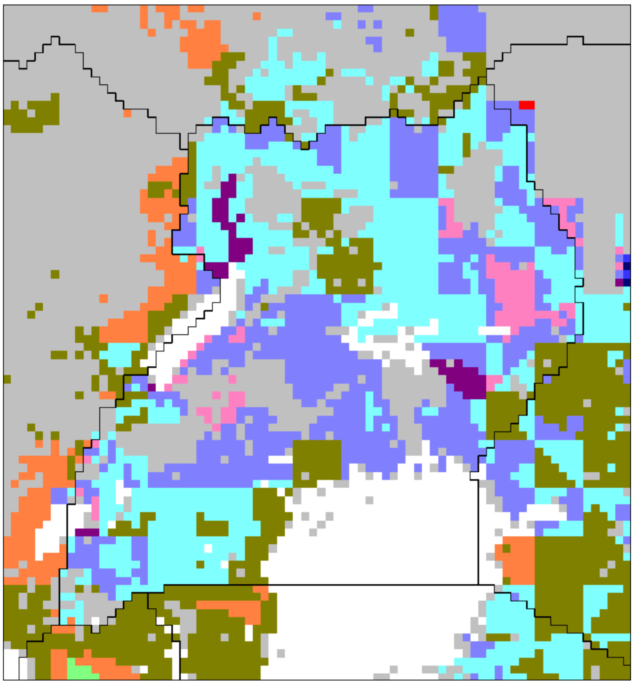


Figure 3.6
Actual maize yield as percentage of calculated potential yield in Uganda (enlarged from the map in Figure 1). Legend as in Figure 1.

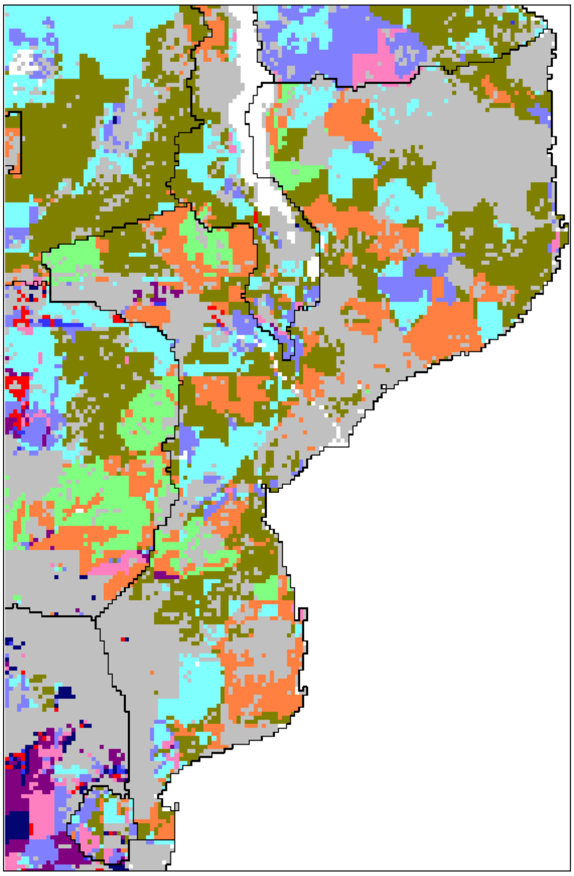


Figure 3.7
Actual maize yield as percentage of calculated potential yield in Mozambique (enlarged from the map in Figure 1). Legend as in Figure 1.

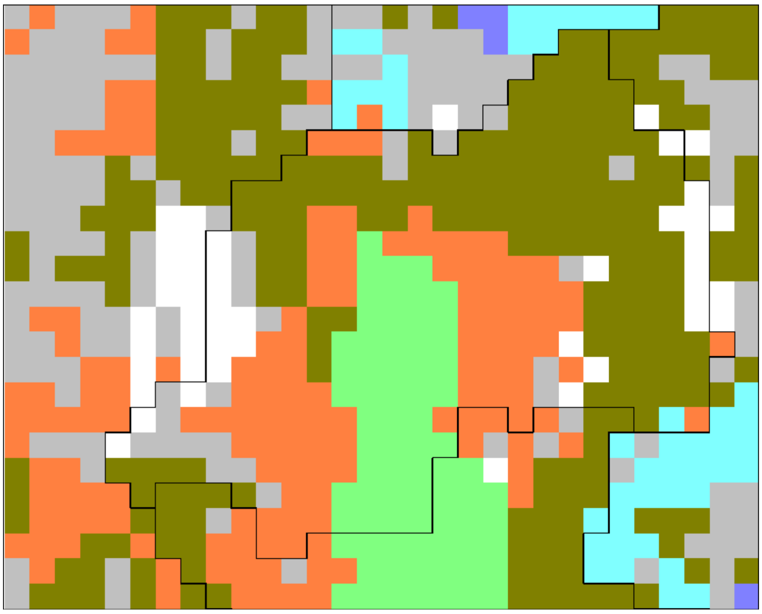


Figure 3.8
Actual maize yield as percentage of calculated potential yield in Rwanda (enlarged from the map in Figure 1). Legend as in Figure 1.

In Conijn et al. (2011) area-weighted average cereal yields (rain-fed conditions, assuming maize/wheat as proxy for cereals) and cropping intensity (total harvested area of crops divided by crop land area) have been calculated for Africa. These results were compared with data from the FAOSTAT database (faostat.fao.org) (Table 3.2). It can be concluded that the potential improvement for land productivity is large in Africa (up to seven times the actual production levels) even without the help of irrigation, which again illustrates the large yield gap in Africa.

Table 3.2
Actual and simulated cropping intensity and cereal yields for Africa.

	Cropping intensity (ha/ha,y)	Grain yield (tonnes/ha)	Combined (tonnes/ha,y)
Actual (1997 - 2003)	0.8	1.1	0.9
Simulated water-limited	1.2	5.8	6.9

3.3 Land use trends in Africa

According to FAOSTAT the harvested cereal area in Africa increased with almost 13 Mha in the period 2000 to 2007 (= 1.9% per year), while cereal yields increased with less than 0.01 tonnes ha^{-1} per harvest (= 1.3% per year; Table 4.1 in Conijn et al., 2011). The total cereal production in Africa thus increased by 3.2% per year and outpaced the population growth in Africa, which increased with 2.4% per year from 819 to 965 million in the same period. A large share of the cereal production increase was associated with an expansion of the cropping area rather than a yield increase. This trend was, therefore, not following the formulated challenge to double the production using half of the inputs (Meinke et al., in prep.). The same trend is also observed for the overall agricultural production in Sub-Saharan Africa since 1960 (Liniger et al., 2011; Henao and Baanante, 2006, in Liniger et al., 2011). The extension of the cultivated areas is associated with the overexploitation of natural resources, causing nutrient mining of already poor quality soils (Breman and Debrah, 2003). The limited access to fertilizers and other inputs have forced African farmers to cultivate less fertile soils on more marginal land (Liniger et al., 2011). The increase of agricultural production in Sub-Sahara Africa is mainly to be realized through intensification of agriculture on already existing agricultural land (e.g. Pretty et al., 2011).

From 2000 to 2007 the total harvested crop area increased with 27 Mha, or 2.0% per year. The fact that this increase is almost equal to the increased area with cereals indicates that the increase of area used for cereals was not realized at the expense of other crops. The total arable and permanent crop land in Africa also increased with 24 Mha (1.5%), or slightly less than the increase in harvested crop areas, suggesting a slightly more intensive use of crop land. The expansion of crop land for agricultural production might have increased the competition with other land use, for example grazing (Van Keulen and Breman, 1990) or could have infringed on biodiversity (Gibbs, 2010).

The production increase was insufficient to substantially reduce the number of undernourished people in Sub-Saharan Africa, which equalled 203.2 million in 2000-2002 and 202.5 million in 2005-2007 (according to FAOSTAT). For northern Africa these figures were respectively 5.6 and 6.1 million.

3.4 Water use

The amount of fresh water production per capita differs widely among countries (Table 3.3 taken from Conijn et al., 2011). Fresh water production in this study is calculated as total rainfall minus total evapotranspiration, and equals approximately total percolation plus total runoff (under rain fed crop production conditions). It can be seen as an output of an ecosystem next to biomass production and can in principle be used for other purposes, such as for groundwater recharge, drinking water, irrigation water, maintaining wetlands, etc. Obviously, the values in Table 3.3 are far from being complete to estimate the actual availability of fresh water, because national in- and outflows of water are not taken into account and inter-annual variation is not made explicit in this indicator. However, the amount of cropland evapotranspiration as percentage of the fresh water production (Table 3.3) reveals that changes in cropland management, e.g. targeted to increase crop yields and crop land ET, can have a dramatic effect on fresh water production (especially in Rwanda and Uganda) and may call for cropping systems that are efficient in water use in those situations.

Table 3.3
Ratios of crop land evapotranspiration (ET, mm y^{1}) relative to total rainfall (mm y^{1}) and total fresh water production (mm y^{1}) and fresh water production per capita for each country. Total refers to the entire country area and crop land only to the part of the country used as crop land (Erb et al., 2007). Calculated values refer to conditions of maize/wheat rain fed yield potentials (source: Conijn et al., 2011).

Country	Crop land ET/total rainfall	Crop land ET/total fresh water production	Fresh water production (m^3 $(cap)^{-1}$ y^{-1})
Benin	12%	31%	4833
Mali	5%	13%	10637
Ethiopia PDR	7%	16%	4876
Mozambique	3%	11%	10878
Rwanda	30%	75%	1120
Uganda	27%	106%	1965

Further research is needed to calculate the fresh water production values for watersheds instead of countries, and to check them at higher spatial and temporal resolution (e.g. per day and at grid cell level). For a complete overview of the available fresh water, other available water sources should be taken into account that determine total water availability in a country, such as in- and outflow of streams, groundwater reserves. A first attempt to consider other sources of available water is done below.

In the six target countries of the Taskforce on Food Security of the Dutch Government rain-fed agriculture is the predominant agricultural production system, as is the situation in the whole of SSA. The withdrawals for irrigated agriculture are generally low (Table 3.4). Ethiopia and Rwanda are upstream countries, not depending on inflow from neighbouring countries. The other countries depend for 40 to 60 % on water resources from upstream countries, but (except for Mali) they still have considerable 'internal' water resources. The figures should be interpreted with care. For example, annual rainfall in Mali is extremely low on average for the country, but this is due to the low rainfall in the part of the country influenced by the Sahara, but in the cultivated part of the country rainfall is higher.

Table 3.4
Key figures of water in irrigated agriculture for six countries in Sub-Saharan Africa (source: FAO, AQUASTAT).

Country	Average annual rainfall	Withdrawals irrigated agriculture (% of renewable water resources)
Benin	1039	0.5
Mali	282	6.6
Ethiopia	848	4.6
Mozambique	1032	0.3
Rwanda	1212	1.6
Uganda	1180	0.5

The relatively low current withdrawals for irrigated agriculture in the six countries should, however, not be misinterpreted. From a water use perspective the intensification of agriculture should be assessed at the regional (river basin) level. Ethiopia, Rwanda and Uganda are situated in the Nile basin, where strict agreements on water use apply. Mozambique is the downstream country of some water-stressed basins. The allocation of scarce water resources in these water-stressed basins should occur on the basis of sound criteria, thus ensuring that scarce water resources are optimally allocated, which implies that priority should be given to the areas where the highest return on water resources can be achieved.

3.5 Nitrogen and phosphorus use and requirements

Based on Conijn et al. (2011), the fertilizer N and P application rates on crop land in Africa were mostly less than 10 kg N ha^{-1} and less than 2 kg P ha^{-1} (Potter et al., 2010; Breman and Debrah, 2003) which is remarkably low compared to other parts of the world. The low fertilizer use in combination with the generally low natural soil fertility is an important factor for the low average crop yields. In countries where more N fertilizer is used (i.e. more than 50 kg N ha^{-1}), for example South Africa, Zimbabwe and Egypt, high(er) production levels are achieved (Monfreda et al., 2008).

In addition to inorganic fertilizers also animal manure can be applied to improve yields and soil fertility. Based on Potter et al. (2010), Conijn et al. (2011) composed a map of manure production (both faeces and urine), expressed per ha crop land. These data can be used to estimate the possible contribution of animal manure to fertilizing crop land. A complicating factor is that part of the produced manure is from grassland (non-crop land). Collecting this manure for use at crop land would result in a net removal of nutrients and a soil fertility decline of non-crop land, which is unsustainable. Collecting manure from animals fed with crops or crop residues and returning these nutrients to crop lands is a more sustainable soil (fertility) management. In Table 3.5 results are presented for the actual and water-limited production situation.

It is concluded that closing the yield gap requires a higher N and P availability to crops (in this example: N and P removal with grains increases with a factor of 7 - 9 and this availability of N and P is much larger than estimated inputs). It is, therefore, not possible to increase the (cereal) productivity in Sub-Saharan Africa and maintain the soil fertility without the use of external nutrient inputs. This conclusion is in line with previous investigations on nutrient balances (Smiling, 1994; Sheldrake and Lingered, 2004; Bremen and Deborah, 2003; Van der Velde et al., 2011).

Table 3.5
Indicative N and P balances and associated yields for cereals in Africa.

	N (kg/ha)	P (kg/ha)	Remarks
Removed grain	15.4	2.5	Based on average actual yield of 1.1 t/ha (FAOSTAT, around 2000)
Removed straw	7.3	1.2	See above, including an assumed harvest index of 0.5
Input chemical fert.	8.5	2.1	Average application rates on crop land in Africa (Potter et al., 2010)
Input organic fert.	26.2	7.0	Estimation based on manure production from Potter et al. (2010) and assumed potential* recovery of 33% (N) and 50% (P)
	➔	➔	Estimated grain yields from N and P balances, respectively: 1.0 – 0.82 t/ha, close to average actual yield (Conijn et al., 2011)
Removed grain	116	22	Based on an average water-limited potential grain yield of 5.8 t/ha (Table 3.2)

* 'Potential' indicates that this is not the actual practice, but the potential recovery under maintained soil fertility of grazing land.

According to FAOSTAT the annual increase rates in fertilizer (N and P) use in Africa during 1997 - 2007 were estimated at 2.4% for N and 0.2% for P. With these rates the additional input of N and P in 2050 relative to 2007 would amount to 21 kg N/ha and 0.2 kg P/ha, which is far too low for the required improvement of yield levels and soil fertility. Especially the situation for P seems critical (data in Table 3.4 suggest that P is more limiting than N because the yield estimations from N and P inputs equal 1.0 and 0.8 respectively) , while the expected increase in the use of P fertilizer is only 0.2% per year. Severe deficits of P-supply were also demonstrated in an analysis of historical maize field trials and demonstrations carried out under the FAO fertilizer programme from 1970-1990 (Van der Velde et al., 2011).

It can be noticed from Table 4 that total input of organic fertilizers exceeds total removal, which indicates an overall unsustainable situation because more organic fertilisers are assumed to be applied than produced on crop land. Either the manure input is estimated too high, or the surplus (input minus removed) comes from animals fed on grassland, in which case there is a risk of nutrient depletion on grasslands (another option, surplus coming from imported feed stuff outside Africa, seems not realistic). Currently, research is being done aiming at a more precise estimation of the minimum fertilizer requirements for given yield levels while maintaining soil fertility. In addition, more information is needed on the fraction recoverable manure that can be used at crop lands in Africa (compare values of 33% and 50% in Table 3.5).

4 Water for agricultural intensification

4.1 Dealing with water scarcity

The intensification of agriculture will require that the limiting production factors be mitigated (Section 3.1), which implies that scarce natural resources should be used more effectively and more efficiently. As water is a critical production factor for agricultural production it should be managed and allocated consciously.

Increasing water scarcity brings about the following sequence of water management practices (in terms of priorities):
1. Supply management ('get more water'): Increase supply (mostly accomplished by water transfers and storage).
2. Demand management/end-use efficiency ('do more with the water'/'more crop per drop'): Introduce water saving technologies (hardware, knowware, orgware) and water saving strategies (such as pricing).
3. Demand management / allocative efficiency ('do better things with the water'): Reallocate water to uses that generate a high value per unit of water.

If the options for supply management have been realized agricultural production can be further increased by reducing losses, for example by introducing efficient irrigation systems, better irrigation practices or crop varieties that consume less water. This should go along with other on-farm management measures (aiming towards precision farming) to ensure that investments have their maximum return. If all options to increase the end-use efficiency have been used, further increase of agricultural productivity may be achieved by reallocating water to the most productive uses. This may have social and political implications, as water rights may need to be withdrawn from existing water users. The increase of the overall (agricultural) production, however, will provide opportunities to introduce compensation schemes, like Green Water Credits (http://greenwatercredits.info/) or payments for environmental services (PES).

4.2 Water productivity

When dealing with water productivity the focus may either be on food security or on income security[2]. In the case of food security the beneficial biomass (yield) of food crops per unit of consumed water is normative (*crop water productivity*). In the case of income security maximum monetary returns on water should be targeted, which means that the monetary value of the produced beneficial biomass (yield) per unit of consumed water, or the *economic water productivity* (also referred to as the 'value of water' or 'net return to water'), should be maximized (Hellegers et al., 2011) (Table 4.1).

[2] For the prioritization of water allocation Hellegers et al. (2011) also consider the job water productivity (number of jobs generated per unit water), water equity and environmental integrity. In this report we will only consider the indicators related to agricultural production.

Table 4.1
Water productivity (production indicators).

Policy objective	Indicator	Description
Food security	Crop water productivity	Beneficial biomass per unit of water consumed
Income security	Economic water productivity	Net private benefits per unit of water consumed

From a macro-economic perspective it is advisable to maximize the economic water productivity. If necessary, the food needed for (growing) populations can be imported and paid for through the revenues of the industry, the services sector and highly-productive agricultural enterprises that produce for the (world) market. From a political or practical (logistical) point of view it may, however, be preferred to focus on crop water productivity (food security), aimed at reducing the dependency of imports and associated fluctuations of prices and supply.

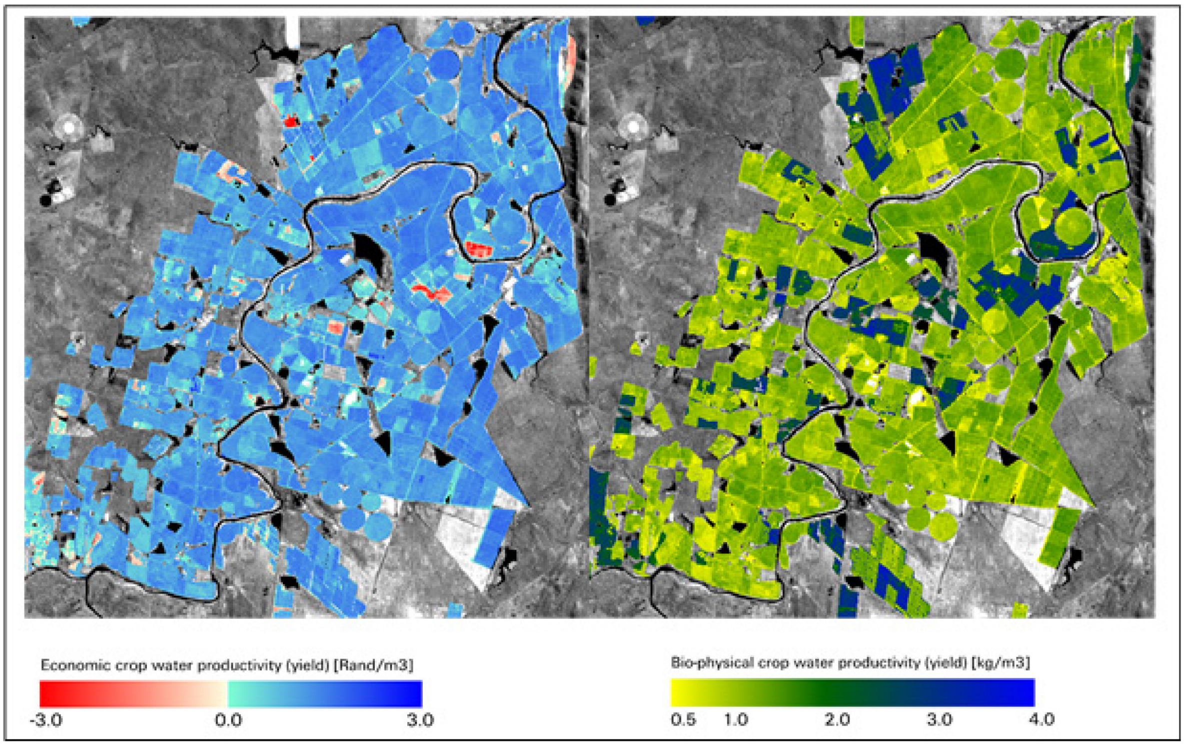


Figure 4.1
Example of crop water productivity (kg/m^3) and economic water productivity (ZAR/m3) of bananas and sugar cane at commercial farms (figure taken from Richard Soppe et al., 2006).

Figure 4.1 presents an example of the calculation of the crop water productivity and economic water productivity, using remote sensing techniques for the calculation of water consumption. The figure indicates that:

1. There is a large variation in crop water productivity and economic water productivity throughout the area.
2. A negative economic productivity may go along with a positive crop water productivity.

A low water productivity for a certain crop indicates potential productivity gains if water is reallocated from the low-productive to higher-productive crops. A large variability of the water productivity of a certain crop in a certain area may indicate potential productivity gains if on-farm management improves. It may, however, also indicate that the crop is vulnerable and that the production system is risky.

4.3 Examples

4.3.1 Incomati basin (Mozambique)

The Incomati river basin is a trans-boundary river basin, shared by South Africa, Swaziland and Mozambique, and a typical example of a basin that is experiencing water scarcity, overexploitation of water resources, population growth, economic development and socio-economic reforms. The basin has a large variety of agricultural production systems, including subsistence farming, irrigated agriculture, pasture, and commercial forest plantations. A large portion of the area is covered by natural vegetation and national parks.

During an interactive workshop stakeholders identified an area of 25,000 ha of bushland to be converted into agricultural land for the cultivation of sugarcane. The proposed area is located in Mozambique. Table 4.2 presents the water productivity indicators for a dry, average and wet year (see Hellegers et al., 2011).

Table 4.2
Situation before and after conversion of 25,000 ha of bush land into sugarcane in Mozambique (from Hellegers et al., 2011). CWP: crop water productivity, EWP: economic water productivity.

	Dry year		Average year		Wet year	
	Before	After	Before	After	Before	After
CWP (kg/m^3)	0.016	0.141	0.023	0.164	0.018	0.146
EWP (ZAR/m^3)	0.002	0.102	0.003	0.116	0.002	0.105
Production value (million ZAR)	6	283	8	321	7	291
Water use related jobs	1086	18028	1086	18028	1086	18028

In the proposed area sugarcane consumes, on average, 35% more water than bush land. As a result the water availability for downstream areas would reduce by 52 million m^3 per year (in an average year). In a dry year, however, the reduction would amount to 85 million m^3 per year. As in dry years there is already no water available from upstream areas, provisions need to be made to cover water shortages, for example through surface water reservoirs or boreholes.

The crop water productivity and economic water productivity will, however, increase considerably. The economic water production value of the area increases from 6 million ZAR/year to 283 million ZAR/year in a dry year and 321 million ZAR/year in an average year. The cultivation of sugarcane also creates about 17.000 additional jobs in the area (Hellegers et al., 2011).

4.3.2 Central Rift Valley (Ethiopia)

The Central Rift Valley in Ethiopia is a closed river basin, characterised by a high population growth, extreme poverty and natural resource degradation. Water resources are being overexploited, resulting in downstream water shortages for people, livestock, agriculture and ecosystems. Land is being overgrazed resulting in severe erosion and loss of productivity (Jansen et al., 2007).

In the basin there has been a shift from rain-fed subsistence farming to irrigated horticulture. Moreover large-scale commercial enterprises have constructed greenhouses for flower production. Both trends infringe on the fragile hydrological system and on water quality.

The estimated economic water productivity is presented in Table 4.3. Although the available information was limited and inaccurate, the table indicates that the economic performance of open-field horticulture is generally poor and associated with low water use efficiencies (situation until 2007). In the case of grapes the economic water productivity may even be negative as a result of low production levels with high costs. The difference in economic productivity between tomato production by smallholders and the state farm is due to the lower yields by smallholders. The economic productivity of the floriculture enterprises is, generally, more than an order of magnitude higher.

Table 4.3
Economic water productivity for various production systems in the Central Rift Valley. Source: Jansen et al. (2007).

Crop	Value of water (Birr m^{-3})
Roses	17 - 29.5
Grapes (state farm)	-0.4
Tomatoes (state farm)	0.6 - 3.8
Maize for hybrid seed (state farm)	0.6
Tomatoes (smallholder)	0.2 - 2.1

It can, preliminarily, be concluded that from an economic perspective, priority should be given to floriculture. It is, however, noted that this assessment only refers to the water productivity. With respect to water quality it was observed that significant emissions of pesticides may occur from the floriculture enterprises (Jansen et al., 2011). The emissions of agrochemicals are also a growing problem in the open-field horticulture. These emissions have repercussions for the sustainability of the production system. This refers to people (polluted drinking water), planet (degraded ecosystems) and profit (low agricultural production by downstream water users).

4.4 Water variability

The previous sections show that the water productivity may largely vary, both spatially and temporally. One of the main contributing factors is the variability of water resources. The crop production and water productivity are largely dependent on the availability of water during the critical growth stages.

In the case of unreliable water conditions farmers will opt for low-risk (and low-investment) production systems, which are, generally, also low-productive. To increase agricultural production and to promote the cultivation of high value crops, reliable irrigation water supply is critical in dry areas. The prioritization of water allocations has, therefore, not only a strategic component, in terms of allocating water resources to certain water uses or production systems, but also an operational component, which implies that discriminate service levels for water provision be applied (and -obviously- discriminate tariff structures).

5 Phases in sustainable agricultural development

Sustainable agricultural development is a process in which various phases can be distinguished (after Moratius and Cochius, 2010, in Vreke, 2010) (Figure 5.1):

1. Creation of awareness in the society of the effects of agricultural intensification, and show actors that investments in agricultural development can be cost-effective.
2. Setting objectives with regard to desired and acceptable effects for the society and for the actors involved in agricultural intensification.
3. Development of strategies to realise these objectives.
4. Implementation of selected strategies.
5. Monitoring and evaluation.

Good communication with stakeholders during the entire process is critical.

The monitoring and evaluation of the effects of agricultural intensification on actors, society and environment ensures a continuous check on the sustainability (Figure 5.1).

Figure 5.1
Phases in the planning of agricultural development.

Creating awareness of the benefits of agricultural development is necessary to diminish the skepsis among potential actors and the civil society in developed and developing countries with regard to investments in rural development, which are often associated with unsuccessful development aid in the past. At the same time, awareness raising needs to address unwanted side effects of agricultural developments, in order to create understanding of measures to prevent or mitigate such effects. These may refer to the environment (e.g. depletion of water resources due to subsidies on irrigation) or to socio-economic effects (e.g. loss of employment for local populations due to the recruitment of foreign workforce).

Objectives with regard to the desired results and acceptable side-effects on the society and the actors should be fine-tuned for the specific type of agricultural intensification or development a particular area. As agro-ecological environments, socio-cultural and economic contexts, and involved actors differ from area to area it is not possible to draft a generic set of directives. To be beneficial for both the individual actors and for the entire society the objectives of intensification should very well consider the capabilities of all actors in the producer-consumer chain (government, producers and the private sector, civil society, NGOs, and knowledge providers, Figure 5-2). Setting objectives which do not match with the objectives of the various actors in the producer-consumer chain of agricultural intensification, or which are not feasible to be realised by these actors, has little chance of success.

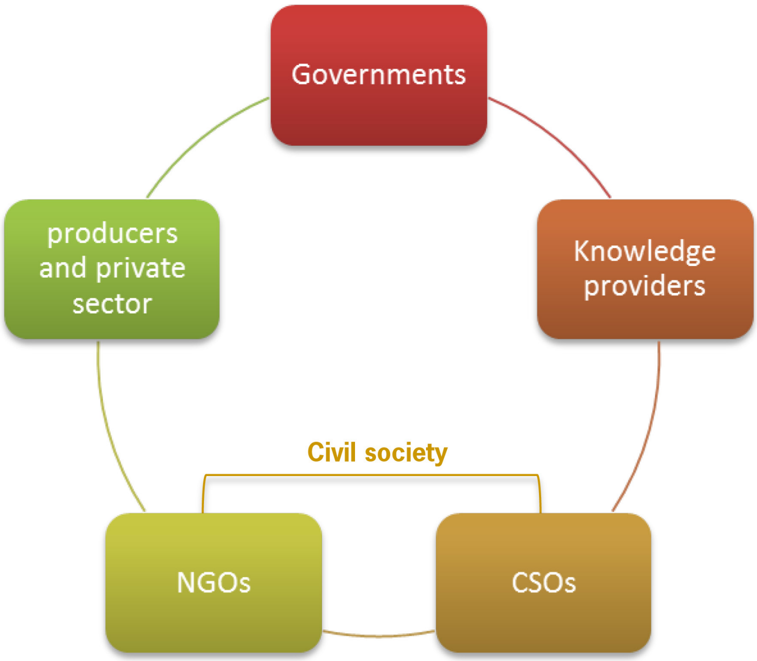


Figure 5-2
Main groups of actors involved in agricultural development. Source: Van Mansfeld (2011).

Strategies to realize the objectives of sustainable agricultural intensification should be developed starting from actors in the (pilot) countries, in close cooperation with the national and regional governments, producers, suppliers, NGOs, CSOs, investors, the Dutch embassies or donors and IFIs. The drafting of the strategies may be supported by the outcomes of the recent policy support missions to the pilot countries. The tool enables the comparison of the identified strategies with existing policies to increase profit/prosperity from agricultural production.

In the **implementation** phase strategies are operationalized. This phase should incorporate mechanisms that promote accountability (Najam and Munoz, 2011). The implementation phase should be carefully **monitored and evaluated,** in order to assess to which degree strategies are sustainable in the selected geographic and time spans. The evaluation of sustainable agricultural intensification includes:

- Testing the degree of sustainability at different scale levels (household/farm, regional and national).
- Comparison of different alternatives for agricultural intensification in order to identify the best strategies, based on expected or delivered performance.
- Comparison the results of agricultural intensification with other approaches to increase profit/prosperity, based on expected or delivered performance.

As previously stated, **communication** on the effects of sustainable agricultural intensification is essential for all stakeholders involved, including government officials, policy makers, producers, suppliers, consumers, investors, NGOs, business & industry. Important motives for communication on sustainable agricultural intensification include (after Vreke, 2010):

1. Exchange of information on the functioning of the agricultural intensification with stakeholders, objectives and results (dialogue).
2. Branding, appeal to convince NGOs and CSOs that sustainable agricultural intensification is possible
3. Inviting partners in the agro-logistic chain to participate.
4. Protection of parties involved in agricultural intensification (e.g. 'licence to produce').

The proposed tool can be used to communicate results of the sustainability assessment due to its simple visualisation of results (see Chapter 7).

6 Guiding principles of the tool to assess sustainable agricultural intensification

6.1 Introduction

Although there are many success stories on sustainable agricultural development or intensification in Sub-Sahara Africa (e.g. Breman and Debrah, 2003; Pretty et al., 2011; Liniger et al., 2011), there is no silver-bullet solution to the sustainable increase of agricultural production, and a direct measurement of sustainability is not possible. There are several reasons. In the first place the concept of sustainable development is ambiguous: there is general consensus that social, economic and environmental aspects of sustainable development should be considered simultaneously when assessing the possible future effect of a policy or strategy (e.g. Olsson et al., 2009). Secondly, the nature and level of sustainable production differs between biophysical and socio-economic contexts. Thirdly, sustainability goals differ between stakeholders within and outside the agricultural sector in a region, and between stakeholders at different institutional levels. Finally, due to complex interactions between natural and human systems, impacts of agricultural intensification on livelihoods, ecosystems and economies vary between spatial scales and in time (e.g. Meinke et al., in prep.). Taking an example from the 'planet' aspect, using surface water for irrigation may have direct effects on water availability in adjacent fields in the same growing season, while groundwater extraction may have delayed effects on the water availability for agriculture at large distances, which may only be noticeable in the course of years.

Current approaches to sustainable development focus on the production chain, i.e. quantifying or at least assessing resource use efficiency and emissions from every step in the chain (e.g. Golden et al., 2010; Kastner et al., 2011; Meeusen and Ten Pierick, 2004). This may be a good approach for comparing sustainability of different products, but it does not tell you what the consequences of resource use and emissions have in specific periods of time and specific places. Our approach is an attempt to include these consequences in our sustainability assessment. This implies that a production chain (step) can be more sustainable in one place than another.

The following starting points for the proposed tool for assessing sustainable agricultural intensification will be discussed here: indicators (6.2), relevant sustainability issues (6.3), dose-response relationships (6.4) and trade-offs (6.4).

Implications for the use of the tool are marked in below each point in grey text boxes.

6.2 Indicators

Since a direct measurement of sustainability is not possible, indicator sets covering the four aspects of sustainability can be used to assess the effects of a development, or policy on each of the aspects. Many frameworks have been developed to assess sustainable development, like the Global Indicator Framework (Olsson et al., 2009), the Sustainable Development Indicators of the EU, the UN Millennium Development Goal Indicators, and the UN CSD Theme indicator Framework (UNDSD, 2007). Some of these sets were developed specifically to assess CSR, like the GRI (2006), the OECD indicator set and ISO 26000 guidelines.

A tool to judge sustainability of interventions, or more specifically agricultural intensification, needs indicators for sustainability, including agricultural production and process indicators. Indicators for agricultural production refer to the target of the required process, increasing agricultural production and improving food security. Process indicators may be integrated in the tool to measure confidence in the ultimate outcome of the process (institutions, governance, organization, public opinion).

Sustainability is commonly divided over people, planet and profit, and in this study we added process. Indicators can be assigned to each of the P's. However, in the context of agricultural intensification it is especially the ratio between indicators expressing profit (e.g. economic performance, like direct economic value generated or distributed) or agricultural produce (as part of the land use efficiency indicator, i.e. the actual crop yield as a % of potential yield) and people/planet indicators (e.g. indicators of land tenure, labour, for people, and indicators of resource efficiency and environmental quality for planet) that count for judging the sustainability of the intervention. 'Does agricultural production increase without drawbacks for the environment, nature, society?' is the question we wish to answer. There is a wealth of literature on sustainability indicators and basically there is little point in presenting a new set. We derived sets of indicators from several sources in the 'More food on smaller foot' project (Noij et al., in prep.), and suggest to use these for assessing the outcome of intervention processes in Sub-Saharan agriculture. In the mentioned project we strived for a set of indicators that links agricultural production and ecosystem services to sustainability and foot print (Table 6.1). It is a quite generic approach, in which agriculture is presented as an ecosystem function providing goods.

Several of the indicators from this approach have been included in the proposed tool.

Table 6.1
Indicators covering ecosystem services, agricultural production, sustainability and foot print from Jansen et al. (in prep.), where indicators have been worked out further.

		ecosystem services			sustainability		nr.
		medicines&genes			resource depletion < regeneration	people	1
	biomass	wood&fibre			resource depletion < regeneration	profit	2
goods		food&fodder			resource depletion < regeneration	profit	3
	primary	water			resource depletion < regeneration	people and prof	4
	productic	soil	suitable=fertile+stable+moisture capacity		resource depletion < regeneration	people and prof	5
	factors	fetilizers	N,P,K,Ca,Mg,S,Fe,tracers		resource depletion < regeneration	people and prof	6
	habitat	connectivity			impacts < resilience/tipping points	planet	7
		biodiversity			impacts < resilience/tipping points	planet	8
		nursery (migr spec)			impacts < resilience/tipping points	planet	9
	agricultur	pest control			impacts < resilience/tipping points	people and prof	10
		pollination			impacts < resilience/tipping points	people and prof	11
		climate	C-sink		impacts < resilience/tipping points	people and plan	12
			microclimate		impacts < resilience/tipping points	people and prof	13
		protection again	storms/wind		impacts < resilience/tipping points	people and prof	14
		weather extreme	flood prevention		impacts < resilience/tipping points	people and prof	15
			drought prevention		impacts < resilience/tipping points	people and prof	16
services	regulation			salt	emissions < buffering capacity	people and prof	17
			water quality	nutrients	emissions < buffering capacity	people and plan	18
				contaminants	emissions < buffering capacity	PPP	19
		environmental	soil quality	salts	emissions < buffering capacity	PPP	20
		quality		contaminants	emissions < buffering capacity	PPP	21
			air quality	filtering	emissions < buffering capacity	people	22
			(waste) recycling		emissions < buffering capacity	people	23
		recreation&tourism				people and prof	24
	cultural	beauty, art, spirit				people and prof	25

6.3 Identification of relevant sustainability issues

There may be a generic set of indicators to derive from, but there is no set that immediately fits/suits a specific region. Selecting indicators using unstructured lists of indicators may result in an unreflected and even biased assessment of sustainable development (Olsson et al., 2009). Identifying aspects of sustainability in the 4 P aspects are relevant in a given region and time, and which indicators are relevant to assess these aspects, is the first step to be taken in a sustainable development assessment (Olsson et al., 2009). E.g. ammonia emission is very relevant within the Dutch context, but it is not a major issue in most of Sub-Saharan Africa. Ideally this should be a joint analysis with stakeholders and/or experts with sufficient local/regional knowledge. It comprises an inventory of environmental functions or ecosystem services at stake, such as urban housing, drinking water, nature reserves, wetlands, fishing grounds, etc., that could be affected by agricultural intensification (Table 6.2). This analysis determines the set of indicators to be monitored/ evaluated, and hence to be selected when using the tool. The level of agricultural development (Input/Output is between Low/Low and High/High) should also be considered for determining relevant sustainability aspects. The output level may be characterized by the yield gap between actual production and potential production, as was done in Chapter 3.2. A typical transformation in agricultural development could be from (very) low input, low output agriculture to high input-high output agriculture. Every phase in this transformation has its own challenges and risks for sustainability. For instance a L/L situation for agriculture in SSA suffers from negative nutrient balances with deteriorating soil fertility and soil degradation. The best remedy would be to increase of nutrient input. However an intervention targeted at a H/H situation may cause emissions of agrochemicals that hamper environmental quality, ecosystem services, nature development and other users/sectors that require clean resources (e.g. urban water use).

The entries for land use type or sector and environmental functions or ecosystem services in the inventory frame of Table 6.2 should be tailored to the region for which the sustainability assessment is performed, and for the Input/Output situation of the current agricultural systems (L/L or H/H, or a level in between). The identification of relevant combinations is recommended to be done as a joint exercise of the 'landbouwattaché' and stakeholders involved in the envisaged agricultural development in the region.

Table 6.2
Virtual example of an inventory of relevant sustainability aspects in the context of agricultural intensification based on present environmental functions and ecosystem services.

	Present Environmental functions or ecosystem services	Water quality	Water quantity	Water safety	Soil quality	Air quality	Culture	Gross product	Employment
Land use types or sector	At local level								
	Other agriculture	X	X		X		X	X	X
	Village populations	X	X	X			X		
	Natural corridors	X	X			X			
	At regional level								
	Wetlands	X	X						
	Nature reserves								
	Urban population	X	X	X					
	Other agriculture	X	X	X	X		X	X	X
	Infrastructure			X					
	Recreation/tourism	X		X					X

6.4 Defining dose-response relations

The next step to identifying/selecting indicators is defining dose-response relations between measures or inputs and effects on the indicators (outputs). This may range from expert judgement type qualitative evaluation in terms of +/- to highly sophisticated deterministic dynamic modelling. The level of investment in this step should be justified by the importance of the D-R relation, i.e. of the indicator to be evaluated. We advocate an approach of stepwise refinement, i.e. start with simple approaches to gain insight in the system as a whole, analyse the sensitivity of the most relevant indicators to 'doses', and subsequently focus on the most determining D-R relations.

In the tool, this step corresponds to the 'scoring' of indicators with reference to the target value of the indicator for sustainable development. Following the recommendation to 'start simple', the proposed 'scoring' in the tool is qualitative, in terms of an improved situation compared to the target value (+1), a neutral situation (0) or a deteriorated situation compared to the target value (-1).

6.5 Trade-offs

A trade-off is a situation that involves losing one quality or aspect of something in return for gaining another quality or aspect. It implies a decision to be made with full comprehension of both the upside and downside of a particular choice (Wikipedia.org). A trade-off is different from an ecological footprint (mainly visible in Planet themes), which implies that steps in the (agricultural in our case) production system lead to harmful effects in other places in the world or in the future (Dolman et al., 2011). The rationale behind displaying trade-offs is that from the perspective of one sector or stakeholder group, trade-offs between the aspects of sustainable development may not be detected if the sector's interest creates a biased view (Olsson et al., 2009). Trade-off can be analysed with correlation analysis and regression analysis. Interpretations may be difficult, because causal relationships between decisions in the production chain, and effects on indicators between which a trade-off takes place, may also affect other indicators. Four types of trade-off may occur as a result of an intervention:

1. Spatial: reduce impact here but cause more impact there.
2. Temporal: reduce impact now but cause more impact later on.
3. Chain: reduce impact in one part of the agricultural production chain but cause more impact in another part of that chain.
4. Theme: reduce negative impact for one sustainability aspect/theme while causing higher impact for another aspect/theme.

Spatial trade-offs

Analysing sustainability implies spatial analysis. The inventory of Table 6.2 already requires spatial analysis, because many dose-response relations for the planet theme are determined by transport of substances through air or water. Socio-economic relations between geographical regions are partly determined by available transport infrastructure. We must not solve one problem here while causing other problems elsewhere. Hence, it is important to distinguish local effects and external effects (Figure 6.1). E.g. effects on soil quality are exclusively local, whereas effects on water and air are always widespread. In the 'More food on smaller foot' project special attention is paid to spatial relations within the river catchment. Of course upstream-downstream relations are very important, both for water quantity and quality. Increasing upstream irrigation might reduce water availability for other downstream agriculture or other water users. Likewise, increased irrigation back flow containing nutrients and pesticides may reduce downstream water quality. Interventions in the water system may cause falling and rising groundwater tables, and may also affect flooding risks.

The selection of spatial scale in a sustainability assessment has three objectives (Olsson et al., 2009): 1. To determine at which scale(s) impacts of the strategy for intensification will be assessed, 2. To relate effects between scales (e.g. farm, regional, national), and 3. To compare the effects on sustainability between different regions.

The spatial scale for the sustainability assessment should be selected before using the tool. The tool is outlined to include the spatial scales of farm/household level and regional/ catchment level. The tool can be adjusted to include other spatial scales.

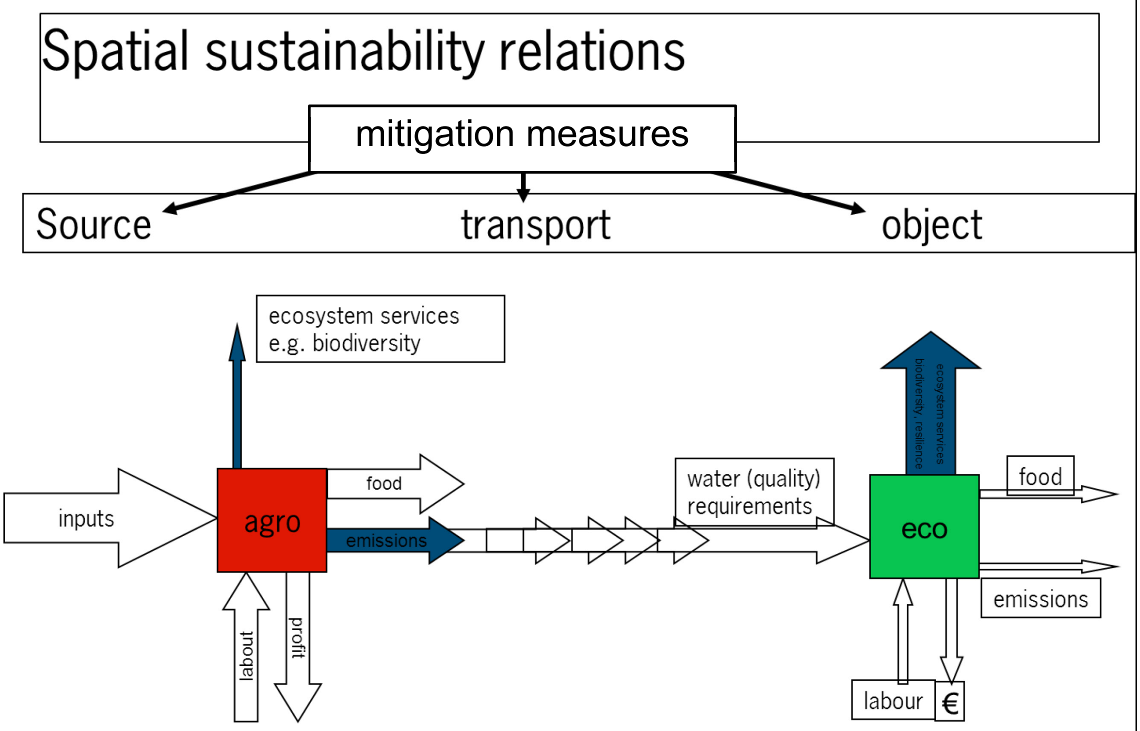
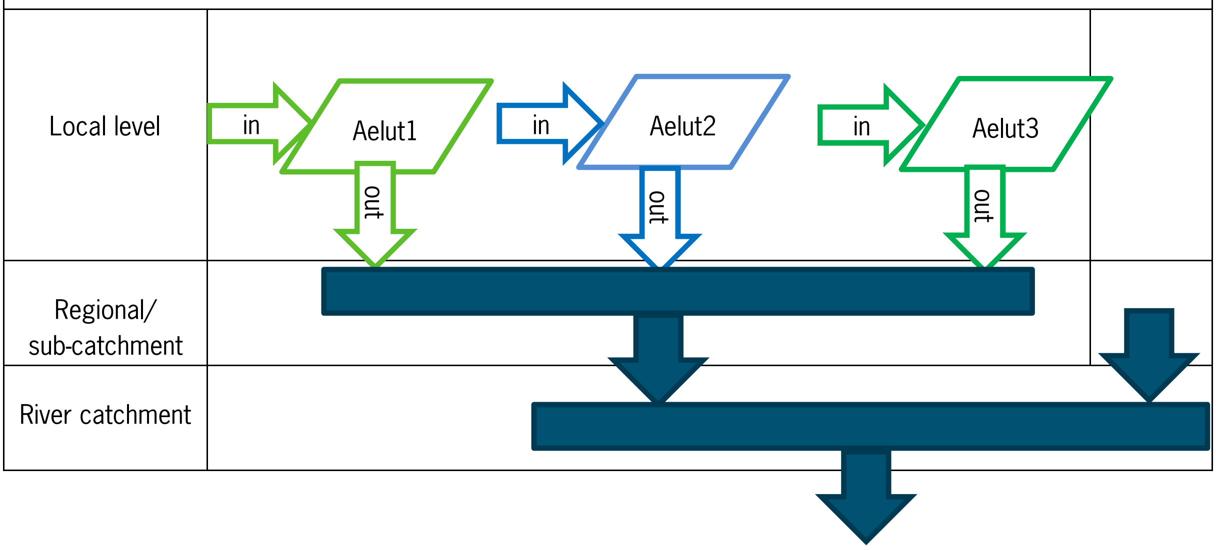


Figure 6.1
Spatial sustainability relation between intensifying agriculture and an ecosystem function at another location as determined by transport through the surface water system.



Temporal trade-offs

In general, it is not possible to produce without any emission or resource depletion. Since depletion and emission both have a rate, the temporal dimension is important, time is at stake. The sustainability question is whether the planet is able to regenerate the depletion before the resource has run out, or to annihilate the effects of emissions before irreparable or unacceptable damage has been done to ecosystems, production systems and humans.

It is important to distinguish between short term and long term effects. A straightforward short term example is water use during dry spells. If farmers do not switch to deficit irrigation during dry spells (saving water by applying suboptimal smaller amounts of water), crops may suffer more serious damage later on. Dealing with the variability of water availability implies short term sustainability management.

However, when we talk about sustainability, temporal trade-off generally refers to longer time scales (future generations). As for emissions the buffer, retention, or decomposition capacity determines the level of the emissions the environment can handle without exceeding unacceptable safety, health or ecological limits (critical loads, expressed e.g. in g/ha/yr) (De Haas and McCabe, 2001). Temporal trade-offs can also be illustrated for depletion of resources, like phosphorus, for which the global reservoir is estimated to last for another 100 years approximately (Vaccari, 2009). As the planet is not able to regenerate P stores at a time scale of generations, we will need to recycle P from waste water and all sorts of (now called) waste material within those 100 years. Relying on this store for generations to come is not responsible, immediate switching to full recovery of P from biomass is not feasible.

The tool has no pre-defined temporal scale. It can be adjusted to include multiple temporal scales similar to spatial scales.

Trade-offs in the production chain

In order to reach sustainable agricultural production we cannot restrict our analysis to primary production alone. Sustainability needs to be evaluated along the production chain. Resource efficiency can be evaluated through life cycle analysis. Rest products and wastes can either be reused for other production processes (cradle-to-cradle) or get lost to the environment. In the latter case resource efficiency will be low. Reuse will be treated as a by-product of the main production process. So, if animal manure containing nutrients is not lost to the environment but used for fertilizing crops it is a by-product of animal husbandry.

Tools and protocols for sustainability assessment of agro-production chains are provided in the KB-project 'Foot printing for sustainability assessment of Metropolitan Food Cluster development' (Van Mansfeld et al., in prep.) and Ten Pierick and Meeusen (2004), and therefore are not part of the proposed tool.

Trade-offs between themes/aspects

Trade-offs between themes and aspects are a logical consequence of any agricultural development with multiple sustainable development targets. An example from the LUPIS project on the assessment of sustainable development policies (Reidsma et al., 2010) is a nutrient management intervention, which would decrease nitrogen leaching by 74%, but increase labour requirements by 19%. A multi-criteria analysis pointed out that the latter had more impact on sustainable development at farm level, based on target values defined for indicators in the social and economic aspects (by stakeholders). This was a reason not to adopt the land use policy in the scenario.

In the further development of the proposed tool, likely trade-offs between themes or aspects should be elaborated in the indicator fact sheets.
The estimation and valuation of trade-offs are by nature subjective, and linked to interests. Therefore these activities should be done in a participatory process with stakeholders. This is recommended for the use of the proposed tool.

7 Application of the tool

The design of the proposed tool is based on the instrument to test the sustainability of Metropolitan Food Clusters designed by Vreke (2010). This instrument uses multi-criteria analysis (MCA), and is organised at four hierarchical levels:

1. Final evaluation of the strategy for sustainable intensification.
2. Aspects on which the evaluation is based. These are the four aspects of sustainability: profit/prosperity, people, planet and process.
3. Criteria within each aspect, and at one level lower: attributes, describing the accountability of actors for processes and external foot prints (ecological and social).
4. Indicators (also called attributes), used to express effects of agricultural intensification on the actors involved and the society in tangible scores. These indicators are at the basis of the tool; they constitute the level at which information and observations for monitoring and evaluation of agricultural intensification are collected.

Below, the steps required for the use of the tool are outlined.

7.1 Problem analysis

This involves the **identification of combinations of sustainability issues and land use types or sectors** relevant in the region, as outlined in Chapter 6, the **selection of spatial and temporal scales** for the sustainability assessment, and a **selection of relevant criteria, attributes and indicators**. This will result in a package of criteria, attributes and indicators relevant to the sustainability assessment.

Additional information on indicators can be obtained through indicator fact sheets, which should be prepared by researchers based on scientific findings, to provide an objective reference to assess the sustainability of agricultural development plans. The fact sheets give more detailed information on the indicators, to assist users in the selection and interpretation of the indicator. Existing indicator fact sheets are available from various indicator frameworks for sustainable development, like the Global Oriented Indicator Framework (Olsson et al., 2009), the Soil Sustainability Assessment indicators (Jonsdottir, 2011), the UN Commission on Sustainable Development indicator set, the EEA Environmental Indicators[3], the performance indicators of the Sustainability Reporting Guidelines (GRI, 2011), and the OECD Environmental Indicators (OECD, 2002). The preparation of the detailed indicator fact sheets was outside the scope of this project. A template for indicator fact sheets and an example are shown in Annex I.

The result of the problem analysis is an 'effect matrix', in which aspects, criteria, attributes and indicators are listed for several alternative strategies for sustainable agricultural intensification (Figure 7.1).

The selection of indicators will depend on the relevant issues and scope of the sustainability assessment. Due to the flexibility provided for selecting indicators, the tool is open to the users' interpretation of sustainability.

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3 http://www.eea.europa.eu/data-and-maps/indicators/

This is consistent with the perspective of several scholars, stating that there is no single operational definition of sustainability (Hanssen, 1996; Robinson, 2004 in: Olsson et al., 2009). The approach taken in the presented tool is that the final selection of indicators, and also the weights assigned to these (step 5), determine the score of a strategy for sustainable intensification, and that this score is influenced by the user's perception of sustainable development. Moreover, fixed indicator lists may limit the possibility of other stakeholders to influence which issues are important (Olsson et al., 2009).

Alternative 1

aspect	criterion	attribute	indicator	Description of situation	Sustainable target value	indicator score	indicator weigth	attribute score	attribute weigth	criterion score	criterion weigth	aspect score	aspect weigth
process												-0.01	1
	stakeholder interests									0.33	1		
		consumer interests						1.00	1				
			fair marketing, information and contracts			1	1						
		product responsibility						0.00	1				
			meeting standards for food safety & product quality			0	1						
		transparent information						0.00	1				
			financial, social and environmental performance			-1	1						
			corporate social responsibility and relationships with stakeholders			1	1						
	fair business									0.00	1		
		corruption control						-1.00	1				
			no slush funds or other illegal advantages			-1	1						
		fair competition						0.50	1				
			fair compensation for intermediairies and legal activities			0	1						
			government			1	1						
		owner rights						0.00	1				
			respect for ownership rights (specifically of land, in relation to land grabbing)			0	1						

Figure 7.1

Example of effect matrix for an alternative. Criteria, attributes and indicators of the aspect Process are shown.

7.2 Setting sustainable target values to indicators

In order to assess the sustainability of an alternative, indicator values should be compared to targets and benchmarks for sustainable development. These target or benchmark values will be specific for every biophysical or socio-economic context, and should therefore be set in consultation with local experts. For example, the question how much soil erosion can be tolerated for sustainable production in a given farming system in a given biophysical and socio-economic context is very hard to answer without information on the context. The loss of soil may be less relevant in areas with deep, fertile soils, or on land used for grazing or ranging. For example, a 'tolerable soil erosion rate' of 1 t/ha.y on agricultural land is considered as a target value for sustainable land use in several EU countries, whereas in other countries, 40 t/ha.y is still considered as 'tolerable' (data from Boardman and Poesen, 2006). Target values of indicators can be based on policy targets, ecological thresholds, general trends and/or expert knowledge (Reidsma et al., 2010).

7.3 Describing the situation of indicators for the alternative(s)

Alternatives are described at the level of indicators in the effect matrix, following the classification or legends that should be described by researchers in indicator fact sheets (see also step 1). An example of an indicator factsheet is included in Annex I. The description is preferably in quantitative terms, at a specific scale and with a specific unit. Methods to assess the indicator, like simulation models or databases, can all be described in the fact sheets (Annex I). Not all indicators can be quantified. This applies particularly to indicators for the process and people aspects, which must be described in qualitative terms.

7.4 Scoring indicators

This involves the translation of quantitative or qualitative indicator descriptions to a qualitative score, which must show whether the indicator indicates sustainable (score +1) or unsustainable conditions (score -1) with regard to the target value of sustainability for the specific indicator (score 0 is indifferent) (Figure 7.2). The translation should be independent from stakeholder perceptions, and should therefore best be done by researchers in the various fields of knowledge reflected by the criteria.

Alternative 1

aspect	criterion	attribute	indicator	Description of situation	Sustainable target value	indicator score	weigth	attribute score	weigth
			NGOs	no NGOs involved	at least one local NGO involved	-1	1		
people									
	autonomy								
		Capacity to deal with power positions						0.00	1
			increased decision-making powers of small-holder farmers	not observed	increased compared to start of project	-1	1		
			participation and leadership for women	50% of involved farmers are women	30% participation of women in initiative	1	1		

Figure 7.2
Example of scoring indicators to sustainable target values.

7.5 Weighting

Weights can be assigned to indicators, attributes, criteria and aspects to express the importance assigned to each by different stakeholder groups involved in a strategy for agricultural intensification. The use of weighting in the assessment introduces the perspective of the stakeholder group on sustainable development in the region of interest. This can be viewed both as an advantage and as a disadvantage. The advantage consists in that, like the EU guidelines for impact assessment state: 'gathering options and information from interested parties is an essential part of the policy-development process, enhancing transparency, and ensuring that proposed policies are practically workable and legitimate from the point of view of stakeholders' (EC, 2002).

7.6 Final assessment

In this step scores on indicators are aggregated to scores on attributes, which are aggregated to scores on criteria, which are aggregated to scores on aspects. This involves averaging the scores on indicators to obtain the score for each criterion, averaging scores of criteria to obtain the score for each aspect, and averaging the scores of aspects to obtain the total score of an alternative. The results of the multi-criteria analysis can be visualised in different ways. These visualisations can be used to negotiate options for sustainable agricultural intensification with stakeholders.

Aspect scores in radar diagram

The coloured surface indicates the total score of an alternative at the level of the four aspects people, profit, planet and process. An example is given in Figure 7.3, in which the score on profit, process and people is high, but low on the aspect planet.

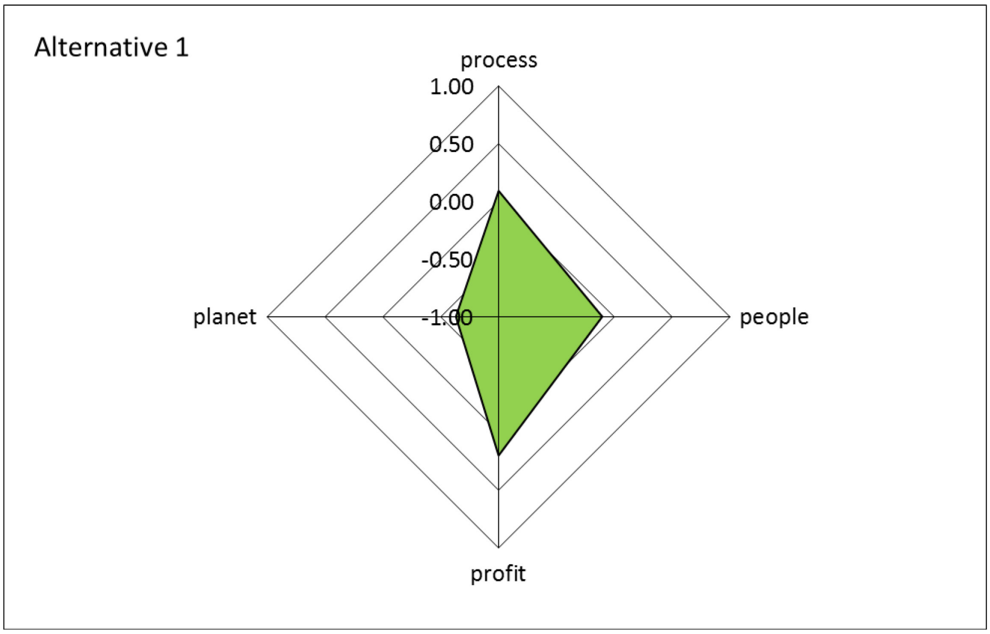


Figure 7.3
Example of aspect scores of a strategy for agricultural intensification.

Aspects and criteria in column diagram
This visualisation shows the relative contribution of scores on criteria for each aspect of sustainability (Figure 7.4). In the example, the large negative score on the sustainability aspect planet is caused by negative impacts of the strategy on resource efficiency and environmental quality.

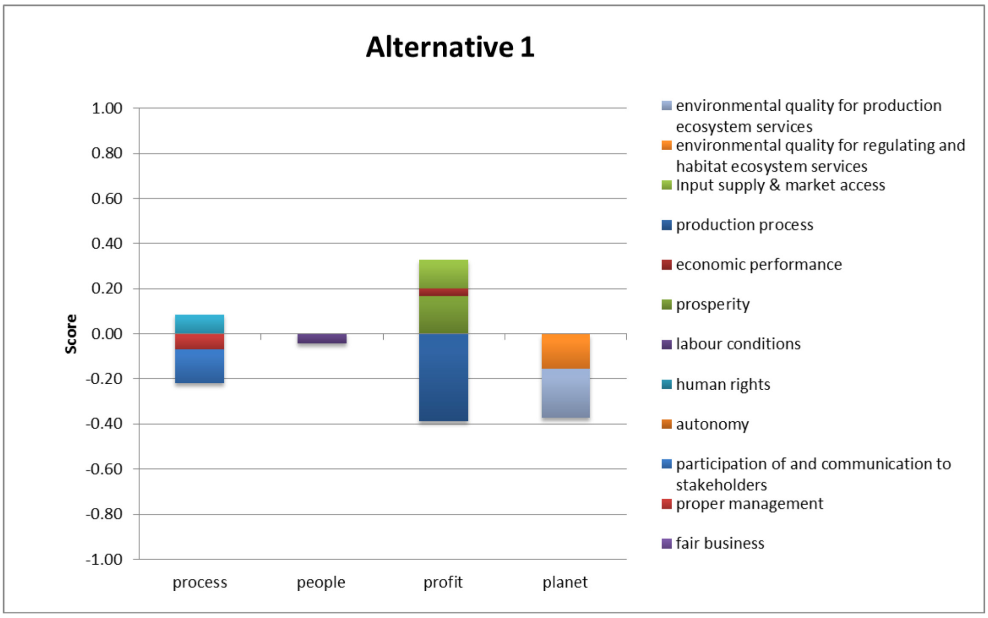


Figure 7.4
Example of scores on aspects and criteria of strategies for SAI.

Total scores and aspect scores of alternatives in bar diagrams
For each strategy for sustainable intensification of agriculture, the total score and contributions to the score by each aspect of sustainability can be displayed in bar diagrams (Figure 7.5 and Figure 7.6). These visualisations help to compare alternative strategies for agricultural intensification.

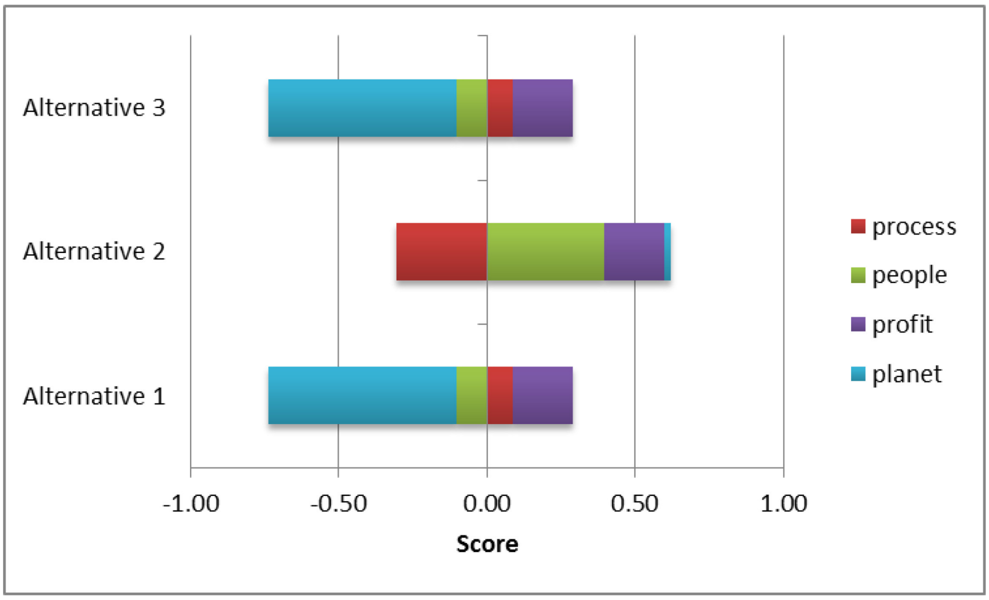


Figure 7.5
Scores on sustainability aspects of strategies for sustainable agricultural intensification.

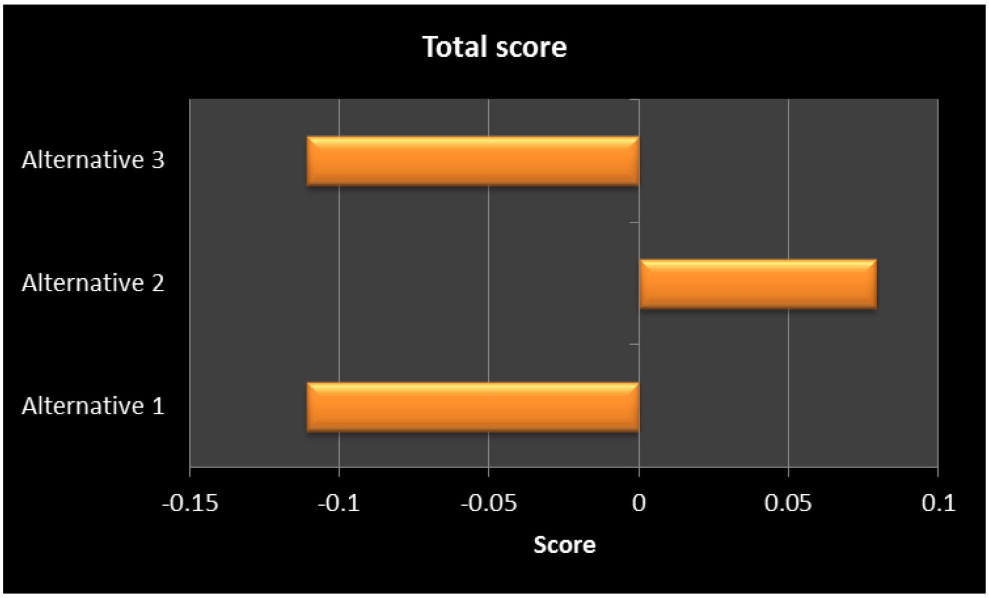


Figure 7.6
Total scores of alternatives, based on weighted scores on aspects of sustainability.

8 Example application of the tool

In order to demonstrate the tool, we applied the tool to an agricultural system with low input and low output in Ethiopia: crop-oriented versus livestock-oriented smallholder farming. This case study from Van Beek in Meinke et al. (in prep.) shows the diversity in nutrient management strategies among eighteen farms in two locations in Ethiopia (Figure 8.1). The case study locations differ in their bio-physical characteristics and therefore in their agro-ecological zoning (Table 8.1).

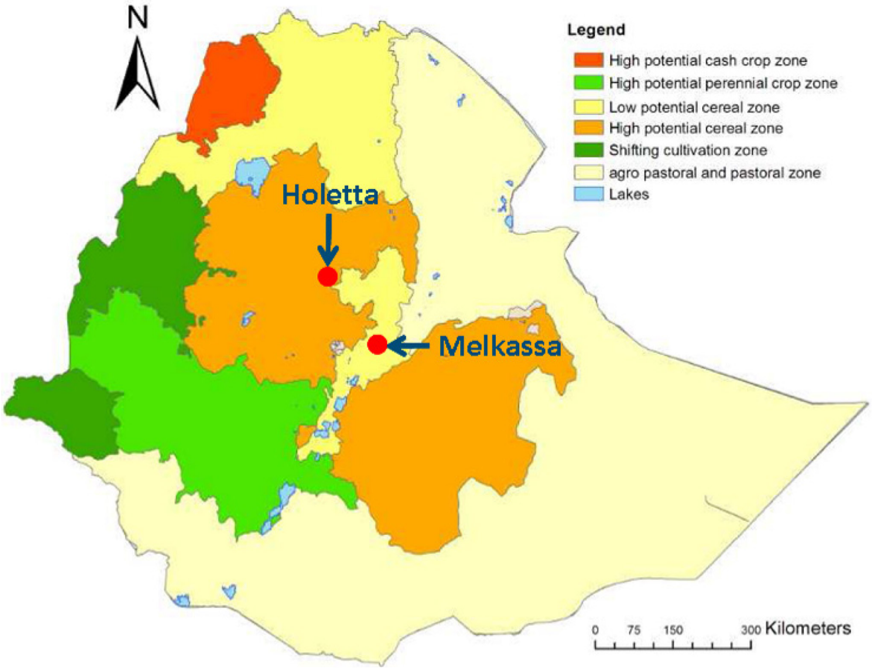


Figure 8.1
Location of case-study areas and agro-ecological zone in Ethiopia (data FAO, 1996).

Table 8.1
General characteristics of site locations Holetta and Melkassa.

	Holetta	Melkassa
Location	Latitude 09°04' N Longitude 38°30' E	Latitude 08°24' N Longitude 39°21' E
Precipitation (mm/year)	1100	546 - 1310
Altitude (m)	2390	1550
Soils	Nitisol and Vertisol	Cambisol, Vertisol, Calcisol
Agro-ecological zone	tepid to cool, moist (moist woyna dega)	Semi-arid and Arid (dry to moist kola)
Major crops	Teff, Wheat, potato Barely and beans	Teff, Sorghum, Millet and beans

Data about farm management, including nutrient management and crop performance, were assessed using the MonQI (Monitoring for Quality Improvement) toolbox (Van Beek et al., 2010; www.monqi.org). The MonQI toolbox is a methodology for monitoring management and performance of small scale farming systems world-wide. Farmers were interviewed on farm management and farm activity using standardized questionnaires. The questionnaire consists of different sections related to the main farm activities (livestock activities, crop activities, etc.). The data collected during the interviews is entered in the software, which combines the farm data with so called background data on e.g. nutrient contents of products, conversion factors from farmer used units (e.g. headloads) to SI units, etc. The software produces a wealth of farm management and farm performance indicators (e.g. NPK balances, gross margins) per activity at plot, compartment and farm level. Interviews were made in November 2010.

Results

The two farming system types were compared with regard to several indicators of the aspects profit and planet, for which information could be found in the case study (Table 8.2). The aspects process and people were not considered in this case study due to missing information.

Table 8.2

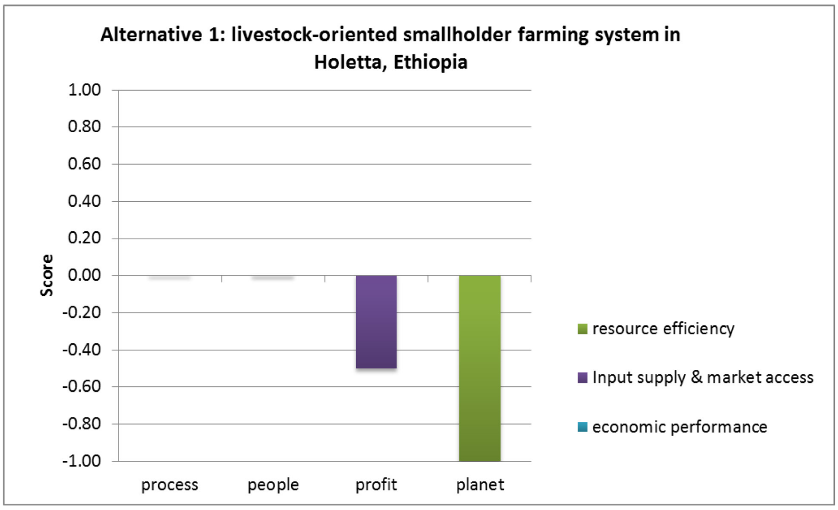
Comparison of farming systems with regard to sustainability indicators.

Case study characteristic	Criterion	Indicator	Holetta	Melkassa
Profit				
Net farm income (1000 ETB/season)	Economic performance	revenues	26	27
GM on crops (1000 ETB/season)			38	34
GM on livestock (1000 ETB/season)			-12	-7
Value-cost ratio of fertilizers for Teff[1]	Input supply & market access	Value-cost ratio of fertilizers	3.2	9.8
Typical crop-livestock ratio (CL ratio)	Resource efficiency	Nutrient reuse	0.40	1.00
NPK balance (kg/farm/season)		Nutrient stock change (kg/farm/season)		
		N	-330	-100
		P	-90	0 - -50
		K	-100	-5 - +20

1 At an N input of 50 kg/ha.

Figure 8.2 and Figure 8.3 show how the two farming system types compare on the sustainability aspects profit and planet. The score on profit is higher for the crop-oriented smallholder farming system, because the value to cost ration for fertiliser was indicated as more close to the sustainable target value. Revenues were similar for both systems, and therefore economic performance has a zero score in both cases.

Both systems had negative scores on planet due to negative nutrient balances. The nutrient reuse was given a lower score in the livestock-oriented system, where larger external inputs to livestock were used compared to the crop-oriented system, and therefore the score on resource efficiency for this system was lower (more negative).



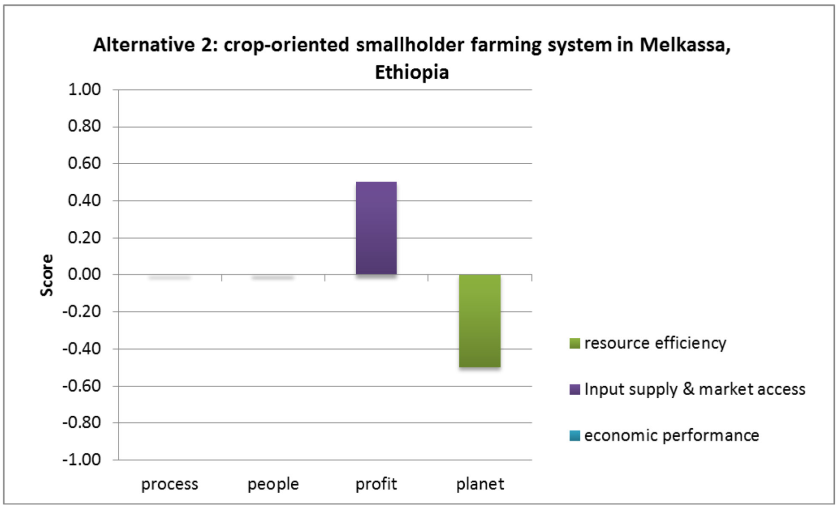


Figure 8.2
Scores on sustainability aspects and criteria for two types of smallholder farming systems in Ethiopia.

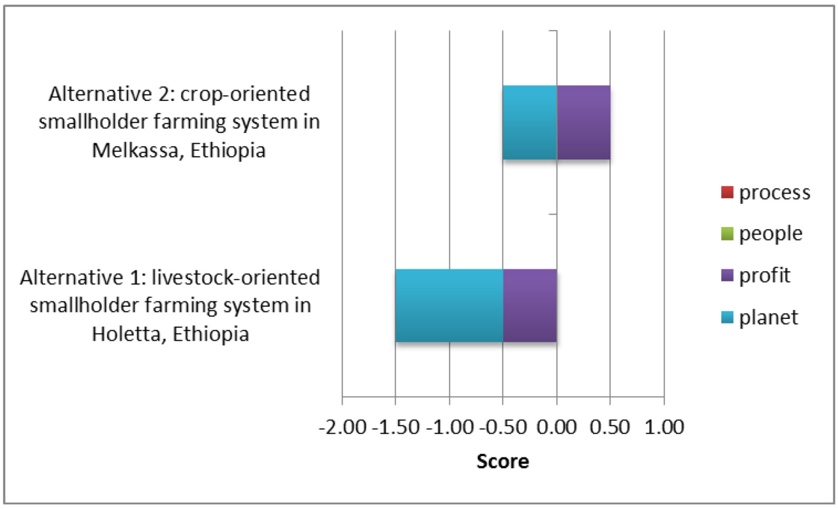


Figure 8.3
Scores on sustainability aspects for two types of smallholder farming systems in Ethiopia.

9 Conclusions and recommendations

The yield gap but also the prospect of economic development in Africa will trigger a lot of effort to increase agricultural production in the coming years. CSD 17 highlighted the need to integrate the increase of agricultural production in Africa with a sound consideration of other relevant aspects to achieve a sustainable production, such as water scarcity, water quality, soil fertility, vulnerability against droughts and climate extremes. By this, and in particular on the way towards Rio +20, CSD 17 provided a landmark calling for **ways to increase the production within given limits**.

The report presented put this request central. In the debate on 'more crop per drop' and the challenge of 'producing more with more, but smarter', the work has focused on identifying corner stones of an approach to enable a smarter production. In this context 'smart' is understood as the capability to plan within given limits, and in particular to include ways to quantify or qualify such limits. These limits are incorporated in the assessment tool developed in this project as **'sustainable target values'**. The work is closely linked to understanding sustainability in the sense of the triple P aspects People, Planet and Profit, with further inclusion of a fourth aspect 'Process'.

Until now there are few frameworks available which allow **a more quantitative sustainability assessment** ('how much could still…') instead of a qualitative check ('sustainable? yes/no…'). Also, in many frameworks, the resource efficiency (under the profit aspect) and environmental quality (under the planet aspect) with regard to **soils and water** are weakly defined. The present report marks a first step with a multidisciplinary group of experts from Alterra and PRI at Wageningen UR to develop a framework enabling mixed qualitative and quantitative assessments of the sustainability of strategies for agricultural development, to support a smarter increase of production in Africa and other regions characterized by resource limitations and fragile environments. The report places an emphasis on soils and water for two reasons:

1. Soils and water are important natural resources for agricultural production in Sub-Saharan Africa, and
2. The framework developed in this study should complement missing information on these resources in existing indicator frameworks for sustainability assessments, both with regard **to resource efficiency** and **impacts on environmental quality**.

Through the inclusion of the four aspects of sustainability, the proposed indicator framework and tool can be used to **facilitate the communication** between policy makers, researchers and stakeholders working in different disciplines. It may stimulate the design and monitoring and evaluation of strategies as a joint process of these actors. The tool may help to **identify priority 'bright spots' for investment in agricultural development** (i.e. with good scores on all four aspects of sustainability). The framework is capable to incorporate different types of trade-offs and spatial and temporal scales.

We strongly recommend to gain a first experience with the framework in a context (strategy, program or project) where options for agricultural development are being identified and selected together with stakeholders as part of a strategy for sustainable agricultural intensification. In such a context, the framework could support all steps of the design, implementation and monitoring of the strategy, following the steps outlined in Chapters 5 and 6, and summarized below. The involvement of researchers from the various disciplines covered by the sustainability assessment (economists, social scientists, environmental scientists, agronomists) is essential to support steps 1b, 1c, 2 and 3.

Steps in the application of the tool for assessing sustainable agricultural intensification

1. *Problem analysis, including:*
   a. *identification of relevant sustainability issues in the area concerned*
   b. *selection of spatial and temporal scales for the sustainability assessment*
   c. *selection of relevant criteria, attributes and indicators*
2. *Setting sustainable target values to indicators*
3. *Scoring indicators*
4. *Assigning weights to the various levels of sustainability measures (aspects, criteria, attributes and indicators)*
5. *Final assessment and negotiation of sustainability options*

Challenges for further developing the assessment tool

A challenge for further developing the assessment tool is to **add forward control mechanisms** in the form of boundary conditions (such as good governance or biodiversity protection) and upstream/downstream feedback interactions, for example with regard to the use of water for agricultural production. The water productivity (either in the crop-based or economic variant) might be a suitable descriptor of such interactions. This indicator of resource efficiency (profit aspect) was elaborated in detail in this report.

Another challenge is **to integrate the four aspects of sustainability**. The presented tool partly allows this by measuring scores on the four aspects on a standardized scale (from -1 to 1), and by integrating scores on the four aspects of sustainability to total scores of alternatives, but this depends heavily on the number of criteria selected in each aspect and the weights attributed to these. In addition, the assessment of agricultural intensification with regard to the four aspects of sustainability gives results based on average conditions over the time frame chosen for the assessment. A challenge is to adapt the tool to take account of changing biophysical or socio-economic exogenous drivers of agricultural production, like climate change and increased climate variability (i.e. to enable 'climate-smart agriculture') or population growth. Climate change and increased climate variability ask for procedures which allow a stronger consideration of dynamic boundary conditions in the drafting of strategies for agricultural intensification.

The results revealed that **quantifying sustainable target values is not a trivial and straightforward issue**. Target values of indicators can be based on policy targets, ecological thresholds, general trends and/or expert knowledge. It is desired to establish a much wider foundation of experience, in particular in linking of theoretical frameworks with demands for the concrete support of agricultural development and stimulation of private sector involvement in practice. Furthermore more understanding is recommendable on when to study enterprises or production systems individually, and when to consider aggregated agro-ecological land use types.

Embedding the approach of assessing sustainability into a wider framework to enable agricultural development and green growth will be a critical step to gain wider acceptance of sustainability assessments, which are already well-known in for example biofuel production and trade. The BO-CI project 'Sustainable Agricultural Intensification without Degradation' (BO-10-011-012) is a start to accompany the new international policies of the Netherlands. More involvement of actual enterprises in the case studies is critical to consider the economic requirements for innovative agribusiness ideas from the beginning, and to tailor the further development of assessment tools to such practical needs.

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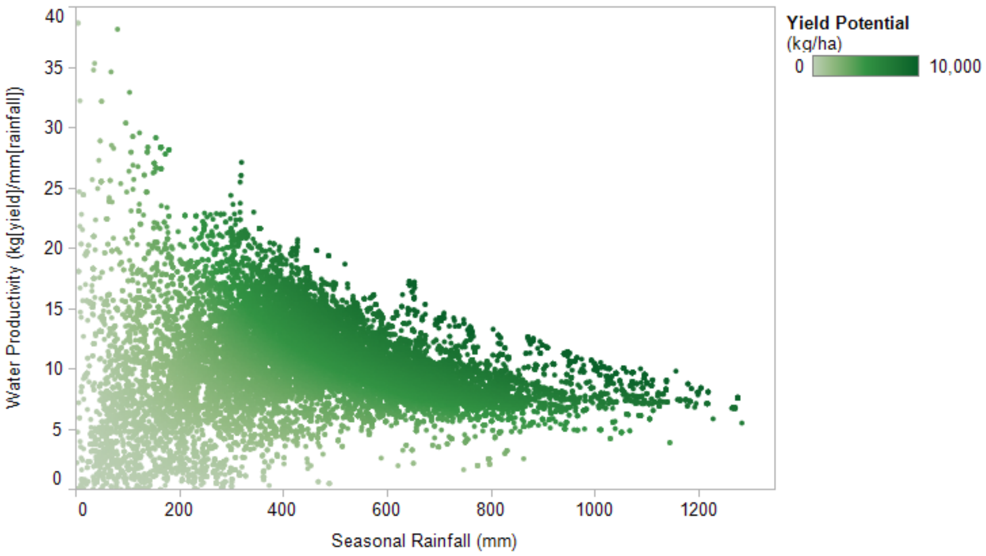
Annex I Template and example for indicator fact sheets

<Name> <Aspect>	
General information	
Units	
Processes described	
Typical spatial and temporal scales	
References	
Detailed description	
Assumptions	
Models, algorithms or databases used	
Reference level for interpretation	
Basic questions of sustainability addressed by this indicator	
Possible trade-offs	
Spatial	
Temporal	
Examples, illustrations, remarks	

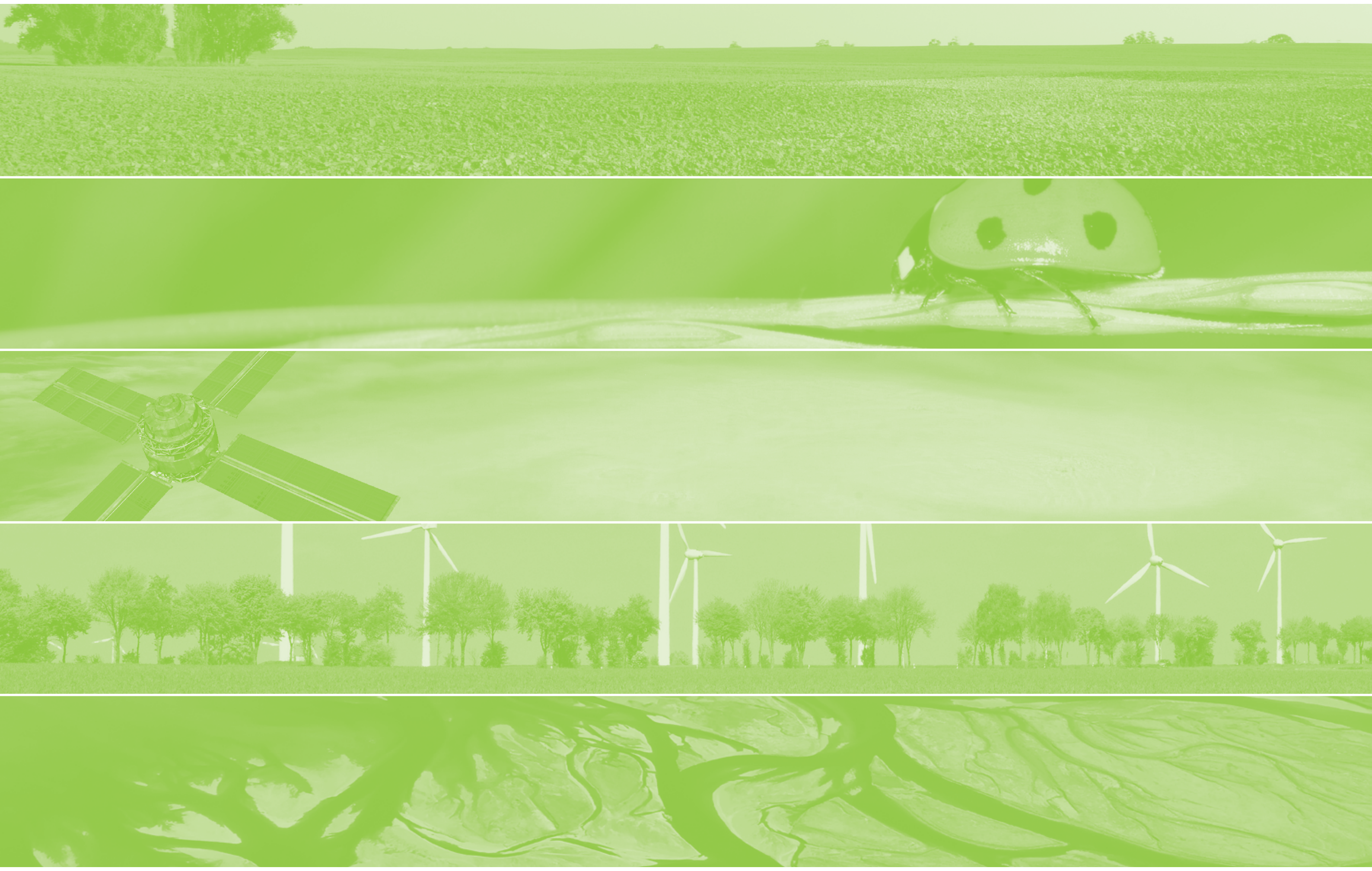
Water productivity - Profit	
General information	
Units	# kg/m^3
Processes described	Water transpired by crops, evaporation from the soil surface and interception by vegetation and crops.
Typical spatial and temporal scales	Field, growing season.
References	Hellegers et al. (2011). http://www.fao.org/landandwater/aglw/cropwater/cwp.stm http://www.worldwatch.org/node/811 http://www-naweb.iaea.org/nafa/news/crop-productivity-africa.html
Detailed description	
Assumptions	Irrigation and other available water can be included or excluded, depending on the efficiency to be assessed and on the spatial and temporal scale for which the efficiency is to be assessed. *Spatial* If water productivity is to be assessed at water system ((sub)catchment) level for comparison of different agricultural production systems, irrigation water available at command level should be included. Irrigation water losses between inlet at the command area and crop evapotranspiration at the field will decrease this water productivity. These losses also comprise water losses due to mismatch between demand and supply and related yield losses. In principle available water for a subcatchment is the rain falling on that subcatchment plus the command inlet. If water productivity is to be assessed for comparison of different agricultural farming systems (farm level), irrigation water available at field level should be included. Irrigation water losses between inlet of the field and crop evapotranspiration at the field will decrease this water productivity, but not the losses between command inlet and field. Available water is the rain on the field plus the irrigation water at field inlet. *Temporal* If water productivity is to be assessed for comparison of different agricultural systems one can choose between seasons corresponding to crop level, and the whole year. For 'season' available water is storage in the soil at the beginning of the season, rain during the growing season plus irrigation water at the field inlet. For 'whole year' available water is the difference in storage in the soil between beginning and end of the season, yearly rain plus yearly irrigation water at the field or command inlet. This approach will include water losses during rainy seasons when supply exceeds crop demand. Both approaches can be relevant. E.g. the whole year approach facilitates water productivity evaluation of scenarios with only one crop or multiple crops per year and includes the effect of anticipating seasonal weather/climate variability. It allows comparison of a farming system with one crop with a long season with two crops with shorter seasons. The season approach allows comparison of water productivity of different crops.
Models, algorithms or databases used	SWAP, SIMGRO, WOFOST, AQUACROP, modellen voor irrigatie efficiency, WaterWise
Reference level for interpretation (order of magnitude, reference level depends on climate zone and crop type, assessment scale)	# kg/m^3 evapotranspired >0.02 (1) 0.01-0.02 (0) <0.01 (-1)

	# kg/m³ (rain+irrigation depth) locally available water >0.01 (1) 0.005-0.01 (0) <0.005 (-1) # kg/m³ (irrigation depth) locally available irrigation water >0.005 (1) 0.0025-0.005 (0) <0.0025 (-1)
Basic questions of sustainability addressed by this indicator	How much crop yield is attainable with the available water resources in the area considered (field or larger)? At which locations and for which crops would an optimal water productivity be attained, given the spatial and temporal distribution of rainfall and the available water for the area considered?
Possible trade-offs	
Spatial	Water extracted upstream for irrigation is no longer available downstream. More efficient upstream rain water harvesting implies less discharge to lower areas, but potentially higher water productivity if upstream rain water is used more efficiently than irrigation water downstream. Upstream irrigation water back flow reduces downstream water quality (salinity). Water not used for agricultural production in one area is not necessarily lost for agricultural production elsewhere. I may be transported elsewhere fast through the surface water system and more slowly through the groundwater depending on the hydrogeology of the catchment.
Temporal	Water extracted from groundwater after a series of dry years is not necessarily replenished in the coming year.

Examples, illustrations, remarks



Water productivity of maize production across Sub-Saharan Africa at district level (expressed with reference to rainfall) as a function of seasonal rainfall. The figure shows that the water productivity trend increases when the seasonal rainfall amount is limited (e.g. below 400 mm), suggesting that investment in water management will be relatively more efficient in those areas. Water productivity varies most for areas with low seasonal rainfall (<200 mm.). Water productivity decreases for areas with higher seasonal rainfall, because in these areas water is not a limiting factor for crop growth. This implies that the reference level for the evaluation of water productivity depends on the climate zone. Source: labs.harvestchoice.org



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