Irrig Drainage Syst (2007) 21:1–15
DOI 10.1007/s10795-006-9014-y

Quantifying the sustainability of agriculture

M. G. Bos · H. van den Bosch · H. Diemont · H. van Keulen · J. Lahr · G. Meijerink · A. Verhagen

Published online: 11 January 2007

Abstract The rural sustainability index is a scientifically based tool to quantify the performance of agriculture. The sustainability of crop production is quantified from three perspectives; people, planet and profit. Within each perspective, one condition was selected that must be met to warrant agriculture. These are: No hazardous work should be used within the crop production chain; agricultural crops should not be grown on land allocated to nature by national law or regulations and, when a GM-crop is present or is introduced in a region, it should not harm development opportunities of other farmers. If these excluding conditions are met, the sustainability of agriculture is assessed through five performance indicators on school attendance, water use and consumption, fertilizer use, pesticide use, and farm income. For each of the five indicators, critical values and target values have been given that limit the transition range between non-sustainable and sustainable production. The five indicators are combined into a sustainability index. The index aims at improving the socio-economic position of farmers while protecting the environment.

Keywords Agriculture · Sustainability · Crop Production · Water · Nutrients · Pest Control · Pesticides · Environment · Income · Education

Introduction

To meet the food-challenge, there are two options; use current agricultural practices and expand the cropped area at the same rate as the growth of world population or improve

M. G. Bos (✉)
International Institute for Geo-Information Science and Earth Observation,
P.O. Box 6, 7500 AA Enschede, The Netherlands
e-mail: bos@itc.nl

H. van den Bosch · H. Diemont · J. Lahr
Alterra, P.O. Box 47, 6700 AA Wageningen, The Netherlands

H. van Keulen · A. Verhagen
Plant Research International, PRI, P.O. Box 16, 6700 AA Wageningen, The Netherlands

G. Meijerink
Agricultural Economic Research Institute, LEI, P.O. Box 29703, 2505 LS The Hague, The Netherlands

practices so that crop yield per hectare increases. To illustrate the impact of (horizontal) expansion of agricultural land, it is good to visualize the area needed. At present about 16,000,000 km^2 land is used for agriculture. A growth of 2.8% per year, matching the growth of world population, would each year require the reclamation of about 45,000 km^2 nature for agriculture. We recommend focusing on the second option so that we can avoid the unwanted infringement into nature areas.

In order to grow, the crop should be sufficient healthy to consume water. Thus plant diseases should be controlled through the sustainable use of pesticides. For the crop to grow, this water must contain "food" that can be transferred into bio-mass. This in turn, asks for the sustainable use of fertilizer. Sustainable rural development is seen as a process that promotes the coordinated development and management of water, land and related resources, maximizing the subsequent social and economic benefits in an equitable (or fair) manner, without compromising the sustainability of vital ecosystems. The sustainability of agriculture therefore has been viewed from five perspectives within the "people, planet, profit" concept. They are related to the; social position of the rural community, availability of water, soil fertility, crop protection and the rural economy.

The structure of the index

As mentioned, the sustainability of agricultural production is viewed from the "people, planet, profit" concept. Within each of these perspectives there is a condition sine qua non that needs to be fulfilled before agriculture can be termed sustainable. These excluding conditions are:

People No hazardous work or child labour[1] should be used within the crop production chain (ILO 2002).

Planet Crops should not be grown on land allocated to nature by national law or regulations.

Profit When a genetically modified crop is present, or is introduced in a region, it should not harm development opportunities of other (non-GM-crop) growers.

If these three conditions are satisfied, the sustainability of agriculture will be evaluated through selected performance indicators.

Which indicators are to be used?

It is important to ensure that indicators, that are selected to quantify the sustainability of agriculture, describe performance with respect to the objectives established for the crop production system and its boundary conditions. A meaningful indicator can be used in two distinct ways. It characterizes the current performance of the production system, and, in conjunction with other parameters, may help to identify the correct course of action to

[1] According to the ILO, "child labour" is, generally speaking, work for children that harms them or exploits them in some way (physically, mentally, morally, or by blocking access to education). Thus, labour during school holidays is not "child labour". In fact, the school year often is designed to fit on-farm labour requirements.

improve its performance. In this sense the use of the indicator as a function of time is important because it assists in identifying trends that may need to be reversed before agriculture can be labeled as being sustainable. A more complete description of desirable attributes of performance indicators is given below (Bos et al. 2005).

Science based An indicator should be based on theoretical or empirically quantified, statistically tested, causal model of that part of the crop production process it describes.

Reproducible The data needed to quantify the performance indicator must be measurable with available technology, reproducible and verifiable.

Transparent Performance indicators should be transparent to the customers of agricultural products.

Manageable This requirement for an indicator is particularly important as implementation is the ultimate goal. Particularly for routine management, performance indicators should be technically feasible, and easily used by policy makers, assessing staff and by farmers given their level of skill and motivation.

Cost-effective The cost of using indicators in terms of finances, equipment, and human resources, should be well within the farmers' income and the monitoring budget.

As mentioned above, the sustainability of agriculture is viewed from five perspectives within the "people, planet, profit" concept. They are related to the; social position of the rural community, availability of water, soil fertility, crop protection and the rural economy. Within each of these five perspectives a long-list of indicators was screened on the above attributes. During subsequent discussions within the team and with stakeholders, the listed indicators were ranked on their impact on sustainability. As a result, five indicators were selected to quantify the level of sustainability (Table 1).

As can be read from the last column of Table 1, there is some interaction between the indicators; e.g. crop yield is influenced by the skills of the farmer, the availability of water and the wise use of fertilizers and pesticides. In turn, crop yield has a major impact on farm income.

Target values and critical values of indicators

Using the attributes on science, reproducibility and transparency of any selected indicator, it is virtually impossible to give a razor-sharp division between the sustainable value and non-sustainable value of an indicator. In practice, the sustainable and non-sustainable ranges of the indicator will be separated by a transition range (Fig. 1). The transition range is bounded by a target value and a critical value. Of both, the numerical values will be explained in following sub-sections.

Customers of end-products

The goal of the Rural Sustainability Index is to promote sustainable crop cultivation and to sell the end-products to customers worldwide. The index can be used to establish links between distributors, manufacturers and farmers, thereby improving the sustainable

Table 1 Selected key indicators for sustainable agricultural production

Perspective	Indicator	Major aspects being assessed by the indicator
People	Percentage of children completing primary school	Ability of farmer to read documentation, manuals, etc
		Level of child labour
		Potential for non-farm jobs for rural population
Planet	Water use and consumption	Water availability
		Crop yield (productivity)
		Drainage of water from field to downstream environment
	Fertilizer use	Potential pollution of groundwater and the downstream environment
		Depletion of soil fertility
		Crop yield
	Pesticide use	Environmental risk downstream of agricultural area
		Potential pollution of groundwater in relation to drinking water safety
		Crop yield
Profit	Gross margin of crop production	Potential income of farmer
		Position of farmer with respect to market

production of food and fiber. Thus, the index aims to improve the socio-economic position of farmers while protecting the environment. These aims must be attained in such a way that the end-product can be sold at a competitive price to (western) customers. Communication thus needs to channel information into two directions:

Farmers (or a cooperative of farmers) need to receive transparent information on the demands set for sustainable agricultural production. Information on recommended changes in crop production practices, needed to improve the level of sustainability, should to be provided through consortia of distributors and manufactures. However, communication with farmers or local cooperatives will be the task of the extension service (or local schooling system).

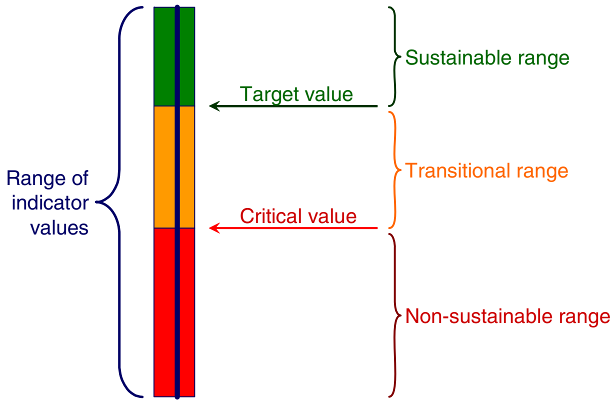
As mentioned before, the index assesses the sustainability of agricultural production from the viewpoint of the consumer of the end-products. It is anticipated that the target consumer desires to contribute to poverty alleviation of rural population in developing countries. It further is anticipated that the customer likes that (rural) development is sustainable. To market products under the Rural Sustainability Index, advertising texts and a paper label are needed that provide transparent information on the method by which sustainability is determined and on the level of sustainability by which the labeled product is produced. The diagram of Fig. 2 may serve for this purpose.

Farmers and the index

Using the Rural Sustainability Index should improve the social and economic conditions of farmers through sustainable on-farm crop production. Since the index is initiated by a group of distributors and manufacturers of agro-related products, they anticipate improving these conditions in three ways (Bos et al. 2005):

- Provide better access by the (cooperative of) farmers to the international market.
- Stimulate that farmers receive a fair share of the world market price for their product.
- Arrange that farmers are being paid in due time.

Fig. 1 Terminology on indicator related values and ranges



Directly related to this "poverty alleviation" aim is the aim to protect the environment. In other words; the present level of sustainability should be improved. Introduction of the index, however, should not exclude farmers from the market if they produce a crop in a manner that is almost sustainable. The term 'almost sustainable' could be defined as: two of the five indicators are red while short-term improvement is anticipated. As illustrated in Fig. 3, it thus is needed to decide on:

- How many indicators are allowed to be red at the beginning of the transition (grace) period. Tentatively it is assumed that two indicators may be red at the beginning of this period.
- How many years (cropping seasons) lasts the transition period? It is assumed that 5 years is an acceptable period provided that progress is made during each year. As shown in Fig. 3, all indicators should be in the sustainable range at the end of this period.

The indicators

As shown in Table 1, five indicators were selected to quantify sustainable crop production within the "people-planet-profit" concept. The following section gives a short description of these indicators with their critical value and target value.

People: percentage of children completing primary school

As was recognized by the Millennium Development Goals (UN 2000); "education is development. It creates choices and opportunities for people, reduces the twin burdens of poverty and diseases, and gives a stronger voice in society. For nations it creates a dynamic workforce and well-informed citizens able to compete and cooperate globally – opening doors to economic and social prosperity."

It is important to note that the indicator measures education of boys and girls. Distinguishing between primary education of girls and boys is important because disaggregated data serve as an indicator for gender equality. In many societies, education

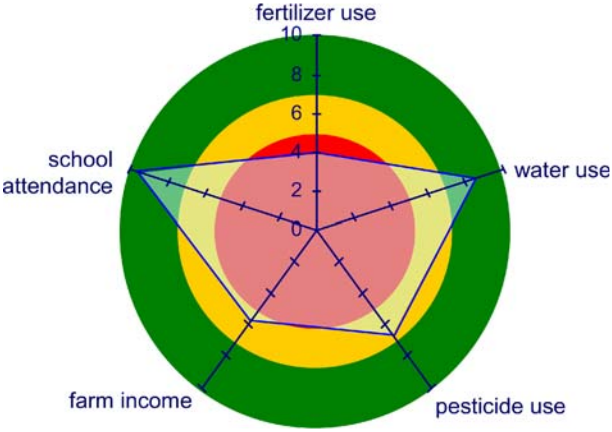


Fig. 2 Graphical presentation of the sustainability index. Sustainable: *all green* (*outer ring*) Nearly sustainable: *no red* and 2 or less (or however many) are *yellow* Non-sustainable: one indicator shows (weakest link in the chain)

rates for boys are higher than for girls. In addition to the criterion of equity it is noted that education of women is extremely important, as it has been shown for instance, that child mortality decreases when mothers have had primary education. Education is important for sustainable production for several reasons:

- When children spend time in school, it means that they are less likely to be involved in child labour.
- Education increases the potential for finding employment outside the agricultural sector. In many societies, the level of hidden unemployment in rural areas is high. With at least primary schooling, people have a better chance to find employment outside of agriculture if necessary.
- Education enables people to read and write, and make calculations. For farmers this is an important skill, because it enables them to read documentation, manuals, etc. Although the number of children completing primary school does not automatically reflect on adult literacy, educating children means educating the farmers of the future.

The ratio is defined as:

$$\text{Completing Primary School} = \frac{\text{Total enrolment in last grade of primary education} \times 100}{e}$$

Where ***e*** equals the number of children in the age-group eligible to participate in primary education according to national regulations.

The '1990 Conference on Education for All' pledged to achieve universal primary education by 2000. But in 2000, 104 million school-age children were still not in school, 57% of them girls of which 94% were in developing countries – mostly in South Asia and Sub-Saharan Africa (Fig. 4). The Millennium Development Goals set a more realistic, but still difficult, deadline. The second MDG is to "achieve universal primary education". The associated target is: to "ensure that, by 2015, children everywhere, boys and girls alike, will be able to complete a full course of primary schooling".

Following the MDG, it is recommended to set the target over a period of years: by 2015, 90 % of all boys and girls alike should be able to complete a full course of primary schooling. It is not realistic to set high targets for the present value of the ratio. The decision of (rural population and farmers) to enroll their children may depend on factors not under

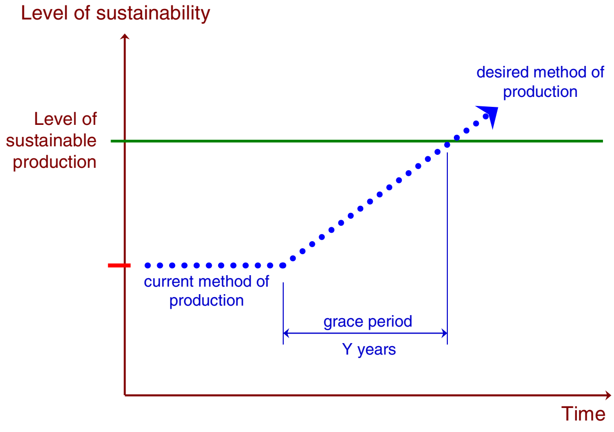


Fig. 3 Transition period (grace period) of the rural sustainability index

their control, such as availability of schooling opportunities, or ability to pay schooling expenses. Although schooling is usually free, there are often expenses such as books, writing materials or school uniforms. Hence, the target value may have to be differentiated among countries or regions. During the transition period, there should be a continuous improvement. The critical value of the ratio is related to Fig. 4. If this percentage for the considered region drops below the average value shown in Fig. 4, we will consider the system unsustainable (critical value).

Planet: water use and water consumption

For a crop to grow, it should transpire sufficient water through its leaves. This water is taken from the soil via the roots. Water also moves into the atmosphere through evaporation from plant surfaces and from the bare soil surface in between the vegetation (following precipitation or irrigation). If sufficient water is available to meet the sum of evaporation and transpiration, this ET will reach its (maximum) potential value, $ET_{potential}$. Otherwise, the actual evapotranspiration (ET_{actual}) will be less than $ET_{potential}$.

To evaluate the adequacy of the available of water within a selected agricultural area as a function of time (throughout the growing season), the dimensionless ratio of actual over potential evapotranspiration gives valuable information to the farmer and water manager. The ratio is defined as (Bos 1997; Bos et al. 2005):

$$\text{Relative evapotranspiration} = \frac{ET_{actual}}{ET_{potential}} \quad (1)$$

The value of this indicator provides information on aspects like; water availability for crop production (yield) and on the drainage of water from the field (area) where the crop is grown to the groundwater aquifer and to the downstream ecosystem. If ET_{actual} is less than about $0.9ET_{potential}$ all available water will be consumed and the volume of drainage water is negligible (Bos 2004). To evaluate the effect of this indicator on crop yield and drainage we refer to the example of a crop production function shown in Fig. 5.

As illustrated, wheat (or any other crop) can only grow if water is consumed. From a farmer' perspective, maximum yield per hectare would be desirable. However, the cumulative ET_{actual} only will approach $ET_{potential}$ if the field is rather wet throughout the

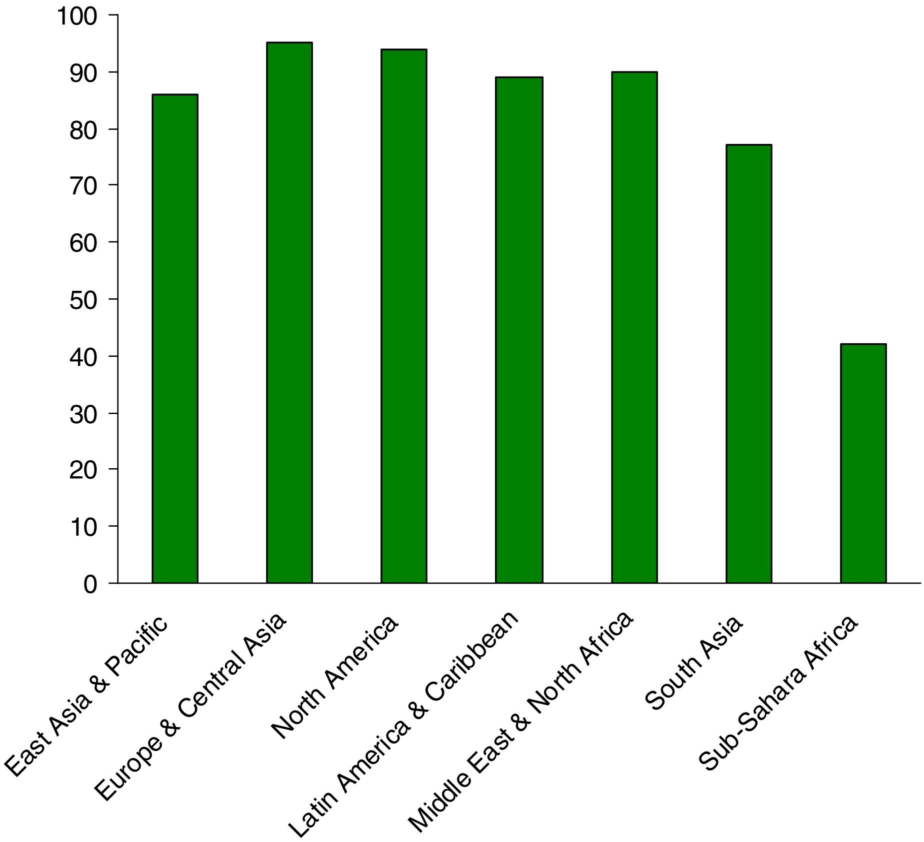


Fig. 4 Average primary school completion ratio for 2000–2002 (after UNESCO 2002)

growing season. Under rain-fed conditions this will not occur during dry spells, resulting in a lower than potential crop yield. Following heavy rain or excessive irrigation, however, ET_{actual} approaches $ET_{potential}$ and the non-consumed part of the water will discharge to the groundwater aquifer or to a stream (drain). This water then may act as the transporting vehicle for pollutants (fertilizer, pesticides) to the downstream ecosystem. Hence, the timing of the application of fertilizer and pesticides should be long enough before an anticipated wet period so that they are not leached immediately from the field. This leaching would result to below target values of the related indicators (see sections on fertilizer and pesticides).

If the cumulative ET_{actual} becomes as low as $0.7ET_{potential}$, wheat yield is maximum in terms of water consumption (in Fig. 5 ET_{actual} is about 2,700 m^3/ha or 270 mm/season). This would be near the target for irrigated wheat (crops) in water-scarce areas. As shown in Fig. 5, yield drops sharply if the ET_{actual} falls below $0.5ET_{potential.}$ At this deflection point in the curve of Fig. 5 ET_{actual} is about 2,100 m^3/ha or 210 mm/season). If meteorological conditions are such that this commonly occurs during the growing season, agriculture production of wheat (example crop of Fig. 5) becomes non-sustainable due to crop failure. Besides, fields with a failed crop are vulnerable to soil erosion.

For the above example, the critical value of the relative evapotranspiration equals 0.5 while the target value is 0.7. The part of the available water that is consumed by the crop

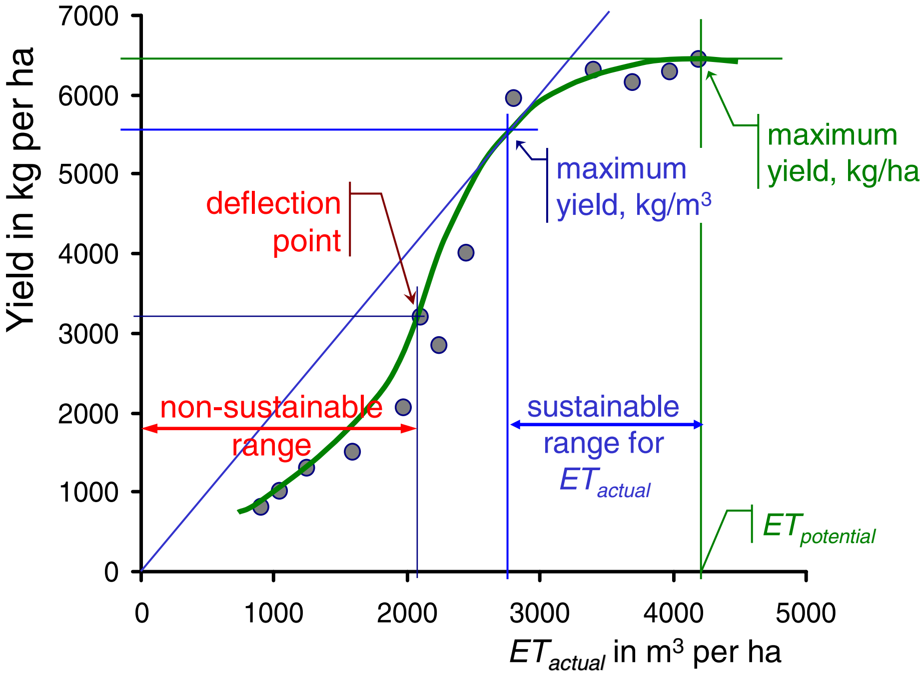


Fig. 5 Example of a crop production function for wheat. In this example potential water consumption by wheat is 4,200 m^3/ha per growing season (10 m^3/ha equal 1 mm per growing season). The figure refers to irrigated wheat, Great Plains, US, (Hanks et al. 1969)

can be increased by farm practices that facilitate the on-field infiltration of water. Most of these practices also reduce erosion.

Planet: fertilizer use

The fertilizer use indicator has been selected to address two aspects: risk of pollution resulting from applying to much fertilizer and mining of soil nutrients related to applying insufficient fertilizer. Representing the effect of fertilizer application in one single indicator is complicated. First we must realize that a major cash crop is often rotated with other crops and effects of soil and fertilizer management are carried over to the following crop. In addition, soil physical and chemical properties influencing the nutrient uptake by the crop and fertilizer losses to the groundwater may vary widely from location to location. Moreover, there are many types of fertilizers with specific chemical composition and application requirements.

This section focuses on two elements that are essential to crop growth and have to be applied from external sources, i.e. nitrogen (N) and phosphorus (P). The widely applied concept of nutrient balances (Smaling 1998; Vlaming et al. 2001; Gachimbi et al. 2002) is used. The *concept* of nutrient balances provides insight in both the economic and environmental effects of fertilizer application. The basic structure of a nutrient balance is most conveniently represented in an input–output diagram (Fig. 6).

Fig. 6 Basic structure of an input–output diagram

The net nutrient balance is the difference between the *input* and *output* components. The storage represents the total stock of a nutrient in the soil, part of which is available for uptake by the crop during its growing cycle. Table 2 shows the breakdown of the *Inputs*, *Storage* and *Output* into basic elements. All inputs, storages and outputs are to be expressed in relation to both N and P.

As nitrogen is required in large quantities by growing crops, and as the soil-plant system is open for nitrogen, it commonly is the limiting factor in arable cropping systems. Applying N (in manure, crop residues, N-fixing crop species, and inorganic fertilizer) is a common agricultural practice to increase crop yields. Using organic sources has additional benefits: improved soil structure, improved soil biology, increased water holding capacity of the soil and increased carbon sequestration. Sources of organic material, however, are limited. When the indigenous fertility of soils often is low, the supply of nutrients in organic form will never be enough to replenish the outputs and the use of inorganic fertilizer is therefore inevitable, the more so as the phosphorus content of organic material is not sufficient to support high production levels.

When too much N fertilizer is applied, or the timing is wrong (see section on water use and water consumption), nitrate leaches to the groundwater or downstream drains (Fig. 7). Most at risks are sandy soils in high rainfall areas where high doses of N fertilizer are applied. Also in irrigated areas with high inputs of N, nitrate leaching risk can be high.

Applying P (rock phosphate or super phosphate) will have a dramatic positive impact on crop yield and, as P is not very mobile in the soil system, leaching is unlikely. The impact of fertilizer application on crop yield will most likely be determined by P, while the environmental impact is dominated by N fertilizer application. As a first approach we define the critical value and target value as follows:

Degradation to the groundwater The concentration of N in the drainage water from the agricultural area must be less than 50 mg nitrate per liter, being the health standard of the World Health Organization (WHO);

Mining of nutrients The effect of mining of nutrients is acceptable when during one specific cropping season less than 10% of the nutrient stock (N or P) is removed.

Table 2 Breakdown in basic elements

Inputs	Storage	Outputs
Mineral fertilizer	Soil organic matter	Crop yield
Organic fertilizer	Soil organic nitrogen	Animal products (meat, milk)
Biological N fixation	Total soil P	Crop residues
Other inputs (deposition, sedimentation, ...)		Losses to the environment (leaching, erosion, gaseous, ...)

Fig. 7 The non-consumed part of the used irrigation water often recharges the groundwaterbasin (aquifer). This water leaches part of the applied fertilizer and pesticides from the field. Monitoring the groundwater table and runoff gives valuable information on water use

Planet: pesticide use

The main objective of the sustainability indicator for pesticide use is to prevent adverse health effects of farmers and operators and to minimize ecological risks of pesticides in ecosystems. The indicator helps to reduce (over)reliance on pesticides for crop production.

The use of pesticides poses health risks to operators of spraying equipment (occupational hazards), to consumers of crops and to the environment. The over-use of pesticides may also lead to a crisis in the agriculture because of a gradual increase of resistance of pest organisms (Castella et al. 1999). Sustainable use of pesticides implies that pesticides may be used to maintain or increase the income of farmers, but without posing unacceptable risks to people and the environment therefore:

- Contamination of spray operators and farm workers should be avoided.
- Contamination of soil, surface water, groundwater and food should be minimized.
- Environmental effects of the pesticides should be minimized.

Table 3 Critical values and target values for selected performance indicators

Indicator	Critical value	Target value
Percentage of children completing primary school	Percentage value from Fig. 4	90%
Relative evapotranspiration	$ET_a/ET_p \leq 0.5$	$ET_a/ET_p \geq 0.7$
Fertilizer use in terms of depletion of stock	output–input $\geq 0.1 \times$ storage	The concentration in the drainage water from the area must be less than 50 mg nitrate per liter
Pesticide use in terms of Exposure Toxicity Ratio (ETR)	ETR ≥ 100	ETR ≤ 1
Gross margin of crop production	Gross margin of other agricultural activities	Gross margin of current method of crop production

In general, these conditions can be met through the application of the principles of "Integrated Pest Management" (IPM; FAO 2004a) or "Good Agricultural Practice" (GAP) (FAO 2004b; Silvie et al. 2001).

The problem in identifying one leading indicator for pesticide use is that many different pesticides are used which behave differently in the environment and cause different types of environmental damage at different concentrations. Therefore, to account for the overall environmental impact of pesticide use, the most relevant modules of the PRIMET approach are used. PRIMET (Pesticide Risks in the Tropics to Man, Environment and Trade) was developed for use in the agricultural sector of Southeast Asia (Van den Brink et al. 2005). It is a decision support system to estimate risks of pesticide applications to aquatic life (by off-field spray drift), terrestrial life, groundwater used as drinking water and dietary exposure.

PRIMET uses a combination of pesticide exposure assessment and risk assessment. Input consists of the amounts of different active ingredients used in a specified area (such as a single farm or the area around a village). The model can be tuned to local circumstances such as temperature, type of water bodies present, soil density, daily drinking water consumption, etc.

Pivotal to the PRIMET approach is the calculation of the "Exposure Toxicity Ratios" (ETR). The ETR's are ratios that provide a quantitative estimate for risk, i.e., the likelihood that a specific toxic effect occurs. The ratio is based on the *predicted environmental concentrations* (PECs) of pesticides and on threshold values for an impact or toxicity parameter, such as the "No Effect Concentration" (NEC) or "Drinking Water Standard" (DWS). Above these threshold values, negative effects of toxic substances are possible. The greater the value of an ETR, the higher is the risk. PEC's are derived using relatively simple model calculations of the environmental fate of pesticides. The relevant indicator values are calculated as:

$$\mathrm{ETR}_{\mathrm{water}} = \mathrm{PEC}_{\mathrm{water}}/\mathrm{NEC}_{\mathrm{water}}$$
$$\mathrm{ETR}_{\mathrm{soil}} = \mathrm{PEC}_{\mathrm{soil}}/\mathrm{NEC}_{\mathrm{soil}}$$
$$\mathrm{ETR}_{\mathrm{Groundwater}} = \mathrm{PEC}_{\mathrm{groundwater}}/\mathrm{DWS}$$

Where:

ETR Exposure toxicity ratio
PEC Predicted environmental concentration
NEC No effect concentration
DWS Drinking water standard

In PRIMET, the terrestrial life module is based on the risk of pesticide use to earthworms. Although earthworms do occur in the more humid areas, it might be more appropriate for arid areas to focus on other key invertebrate organisms, such as termites, ants and/or scarabid beetles. Toxicity data for these species should in that case first be collected.

The PRIMET system includes several series of model calculations using a number of input variables. It is beyond the scope of this report to present all of them (van den Bosch et al. 1998; Van den Brink et al. 2005). However, basically three types of input can be distinguished.

- Variables that characterize local environmental conditions in an area or field: hydrology, soil type, climate, etc.;

- Basic properties of the pesticides used: environmental behavior, degradation, toxicity;
- Parameters that describe pesticide use: number of applications, dose applied, frequency of the applications.

Environmental variables can be measured and/or specified per farm, per community, per region or per country. Especially those on climate and soil may apply to larger areas. Some characteristics are site-specific. However, once these characteristics have been measured they can be used for all future indicator calculations in the same area. Various pesticide properties are available in literature or in files submitted for pesticide registration; others probably need to be requested from pesticide manufacturers. No Effect Concentrations (NEC) are derived from standard toxicity tests, some of which are required for registration of the pesticide. Drinking water Standards (DWS) are often set by governments or international organizations. When these basic properties of the pesticides are known, they can be used in all calculations and for all areas and countries where the same substances are used in agriculture. The site- and pesticide-specific information is gathered once and needs little updating; say every 5 years. It should be kept in a database and be made available for parties involved in monitoring of the pesticide indicator.

The most elementary input to the PRIMET model consists of data on pesticide use. This information is specific for individual farms or areas and varies with time. The best way to collect these data is through the use of questionnaires. These can be completed by farmers or by personnel involved in farmers' organizations. These data should be collected on at least an annual basis, because pesticide use patterns vary considerably from year to year depending on infestations by particular pests and the availability of particular pesticides on the market. Hence, the pesticide indicator would benefit greatly from a system in which farmers would permanently keep their own records of pesticide use.

It is recommended to calculate the ETR for surface ware, soil and groundwater. Judgment of the sustainability of pesticide use should be based on the highest of the three calculated ETR values. The non-sustainable range for the ETR is equal or greater than 100. The target value is 1.0 (ETR$\leq$1.0 is sustainable).

Profit: gross farm income

Since the index is initiated by a group of distributors and manufacturers (Bos et al. 2005) of agro-related products, it is assumed that farmers receive a fair price for their cash-crops. This will contribute to improving their livelihoods. There is also a link to the other indicators. For Planet: if producers receive low prices for their crop, they will have less opportunities to invest in their farms, for instance to buy fertilizers to replenish soil fertility. For People: when households have more income, sending their children to school will become easier, because they can pay school fees, books, etc., or they can hire labour to work on the farms (instead of relying on the labour of their children).

However, due to the set-up of agricultural markets in various countries, it is uncertain whether farmers will receive a higher price for their cash-crop, even if they turn out higher quality crops. There are various reasons for this uncertainty:

- In many countries, there is no price competition. The crop price is set (by the government) in advance and may be adjusted when world prices rise during the season.
- Prices often apply to a whole region or even a whole country. The same price applies to all producers, regardless of their location.

- Although the crop value chain has been liberalized in many countries, this has not led to a competitive market. Usually producers have only one ginnery, mill, etc to where they can sell their crop.
- In general the crop marketing chain remains heavily regulated with a large influence exerted by the government.

Thus, we need an indicator to measure economic sustainability of the production of a cash-crop. Because the indicator needs to be cost effective to measure, we will focus on the gross margin. The gross margin is the difference between the gross income and variable costs of growing a crop (and does not include overhead costs). Gross margins allow comparison of the relative profitability of alternative cropping options that have similar land, labour, machinery and equipment requirements. Comparisons may therefore be made of a dominant cash-crop in the region and alternative crops. The gross margin is a reasonable measure of the relative profitability of activities with similar demands on farm resources. It is defined as:

$$\mathrm{GM}_{\mathrm{crop}} = P_{\mathrm{crop}} \times Q_{\mathrm{crop}} - \sum \left(P_{\mathrm{input}} \times Q_{\mathrm{input}}\right) \tag{2}$$

$\mathrm{GM}_{\mathrm{crop}}$	Gross margins of the considered cash crop
P_{crop}	Price of the cash crop
Q_{crop}	Quantity of cash crop sold
P_{input}	Price per unit of all inputs (fertilizer, pesticides, seeds, hired labour
Q_{input}	Quantity of input units

Gross margins are expressed in a standard unit, for example per hectare. For sustainability considerations, it is not recommended to calculate the gross margin for each farmer, but on the basis of average values. Such an average gross margin would be available at agricultural statistics offices, or can be collected from a sample of farmers.

The gross margins per hectare for the major cash crop must be higher than those for other agricultural activities. Otherwise, if allowed and markets are available, farmers will start switching from production of this crop to other activities. Secondly, the gross margins of an alternative (improved) method of crop production must be higher than those for the current method of crop production.

The critical values and target values of all five indicators are summarized in Table 3.

Acknowledgements The Rural Sustainability Index was developed as part of the "Cotton Made in Africa"® project. The index was discussed with cotton producers, manufactures, distributors, international funding agencies and with NGO's. Presently, the index is used in three cotton producing countries in Africa (http://www.cottonmadeinafrica.com). The project was partly funded by the Michael Otto Foundation, Hamburg, Germany.

References

Bos MG (1997) Performance indicators for irrigation and drainage. Irrig Drain Syst 11(2):119–137 Kluwer, Dordrecht

Bos MG (2004) Using the depleted fraction to manage the groundwater table in irrigated areas. Irrig Drain Syst 18.3:201–209 Kluwer, Dordrecht

Bos MG, Burton MA, Molden DJ (2005) Irrigation and drainage performance assessment: Practical guidelines. CABI, Wallingford, UK, p 154

Castella J-C, Jourdain D, Trébuil G, Napompeth B (1999) A systems approach to understanding obstacles to effective implementation of IPM in Thailand: key issues for the cotton industry. Agric Ecosyst Environ 72:17–34

FAO (2004a) http://www.fao.org/ag/AGP/AGPP/IPM

FAO (2004b) http://www.fao.org/icatalog

Gachimbi LN, de Jager A, en H, Thuranira EG, Nandwa SM (2002) Participatory diagnosis of soil nutrient depletion in semi-arid areas of Kenya. Manag Afr Soils 26:15. IIED, London, UK

Hanks RJ, Gardner HR, Florian RL (1969) Plant growth – evapotranspiration relations for several crops in the Central great Plains. Agron J 61:30–34

ILO (2002) Every child counts. New global estimates on child labour. ILO, Geneva

Silvie P, Deguine JP, Nibouche S, Michel B, Vaissayre M (2001) Potential of threshold-based interventions for cotton pest control by small farmers in West Africa. Crop Prot 20:297–301

Smaling EMA (Ed.) (1998) Nutrient balances as indicators of productivity and sustainability in Sub-Saharan African agriculture. Agric Ecosyst Environ, Special issue, 71(1,2,3):346

UN (2000) Millennium Development Goals, http://www.un.org/millenniumgoals

UNESCO (2002) Statistical database. Updated 2004-069-15. Available at: http://stats.uis.unesco.org

van den Bosch H, De Jager A, Vlaming J (1998) Monitoring nutrient flows and economic performance in African farming systems (NUTMON). II. Tool development. Agric Ecosyst Environ 71:49–62

Van den Brink PJ, Ter Horst MMS, Beltman WHJ, Vlaming J, van den Bosch H (2005) PRIMET version 1.0, manual and technical description. A decision support system for assessing pesticide risks in the tropics to man, environment and trade. Alterra Report 1185. ISSN 156-7197

Vlaming J, van den Bosch H, van Wijk MS, de Jager Ar, Bannink A, van Keulen H (2001) Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON). Part 1. Manual for the NUTMON-toolbox. Alterra/LEI, Wageningen, 's Gravenhage, the Netherlands