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Important questions to be answered by environment statistics in sustainable crop production intensification (SCPI)

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The sustainable intensification of crop production seeks to put mainstream agriculture firmly into partnership with ecology on multiple complementary fronts. Different types of indicators are needed at multiple scales, including down to the most local, farm level since key resource allocation decisions in agriculture – how farming is to be done - are taken by local institutions, communities or individual farmers.

Introduction

1. Agriculture is the stated activity of around 2.5bn people, globally; agricultural use of land (around 37% of global total, including managed forests and grasslands), and water (70% of total freshwater withdrawn) is of a scale to have a potentially significant impact on the environment. [1] Certain agricultural practices are implicated in progressive loss of forest resources, land degradation, reduced water and air quality. At the same time, agriculture is faced with the need to respond to ever-increasing demands for food, feed and fibre, and to provide employment and support to rural livelihoods. Reconciling agricultural and environmental perspectives on resource use will be critical to ensuring "future environmental sustainability" (in the terms of MDG 7). One key to this is a solid and agreed set of data, and derived indicators, at multiple levels.

2. The purpose of this paper is to look at environmental sustainability from an agricultural perspective. It begins with some introductory remarks on environmental statistics and outlines the main domains of FAO's interest in the subject.[2] It goes on to present sustainable agricultural intensification as a key consumer of environmental statistics, both to help establish baselines and to monitor progress towards agreed / negotiated goals.

Environmental statistics and FAO

3. In the light of concerns about climate change and the sustainability of resource usage, a number of recent initiatives have sought to give direction to global work on environmental statistics. The aim has been to extend an ecological view throughout analyses.[3] At the same time there has been a desire to improve consistency (through harmonising definitions of key terms and methods), and to allow ecological

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[1] State of Food and Agriculture Report (SOFA), 2007, Annex A (FAO)

[2] defined in the original UNSD publication the Framework for the Description of Environmental Statistics (FDES) as (a) covering natural phenomena and human activities that exert impact on the environment...(b) providing a synthesis of data from different subject areas and statistical sources; (c) covering both qualitative and quantitative aspects of the environment; and (d) consisting of conventional statistics, monitoring data, remote sensing information, etc

[3] As recommended by key review paper of UNSD in 2001; and subsequent development of methods such as the D(rivers)–P(ressures)–S(tate)–I(mpact)-R(esponse) analysis

sustainability to be judged alongside the more traditional measures of development. For instance:

- The Convention on Biological Diversity identifies two major indicators relevant to agriculture – the area of land under sustainable management, and the volume of production derived from sustainable sources. This is supported by the Biodiversity Indicators Partnership (2010)
- OECD Environmental Outlook to 2030 (OECD, 2008) specifically identified agricultural water use and pollution as one of its "red light" issues, while also underlining that "many environmental challenges cannot be solved by environment ministries alone".
- "Gross Domestic Product (GDP) and beyond – measuring progress in a changing world" (EU, 2009);
- London Group on Environmental Accounting (one of a number of groups of UN statisticians working on methodological problems in statistics) focusing on the link between environmental accounting and Systems of National Accounts;
- Sachs et al (2010, Nature) identified at least 18 networks of monitoring environmental statistics relevant to sustainable development, while noting that many are not using a common set of information management tools, and advocating a global system of monitoring stations to gather data and build on existing initiatives;[4]
- NGO networks such as the ISEAL (the International Social and Environmental Accreditation and Labelling) alliance, whose members are "leaders in their fields, committed to creating solid and credible standard systems that give business, governments and consumers the ability to choose goods and services that have been ethically-sourced but most of all help the environment and guarantee producers a decent living";
- the Millennium Ecosystem Assessment[5] (2005) included a multivolume analysis of the multiple functions of ecosystems in supporting human well-being, notably agriculture; it developed four major scenarios of future development and examined likely impact of the scenarios on 20 representative ecosystem services – benefits people derive from the ecosystem;

4. FAO is both a major source and a major user of environmental statistics. Since 1992 - and reiterated most recently in the Medium Term Plan of Work, 2010-2013 - FAO technical departments have focused on sustainability issues in agriculture and rural development, and there are a number of programmes looking at issues such as:

[4] Sachs et al, "Monitoring the world's agriculture", Nature, 29 July 2010, pp 558-560. With regard to improved harmonisation and information management, revision of the Framework for the Description of Environmental Statistics (November 2010) provides an ideal opportunity to refine this important and most relevant global public good.

[5] the Millennium Assessment defined ecosystem services as being provisioning (production of food or water), regulating (climate change, natural pest and disease control, pollination) or cultural (recreational or spiritual – see www.maweb.org

- the sustainability of fish stocks under current and projected future exploitation (implementing the Code of Conduct for Responsible Fisheries)
- forestry resource assessments (see Box 1)
- sustainable livestock practices
- sustainable crop production intensification
- sustainable natural resource management (land and water, as well as the impacts of climate change, and growing production of biofuels, on food security)[6]

FAO has a global normative role in gathering statistics associated with food and agriculture in the interest of improving food security. These include both production statistics in domains such as crops, livestock, fisheries and forestry, *and* environmental statistics related to natural resource usage (such as land, water, fish stocks or forest resources, genetic resources, etc). These two major sets of data are complemented by statistics on key inputs such as mineral fertiliser, pesticides and energy.

5. FAO produces global public goods in the area of statistics, for instance by assembling data from Member States' statistical services, validating and publishing the key agricultural database in this area (FAOSTAT).[7] FAO also uses this and other databases (on land use, climate change, etc) for modelling and projections, and facilitates work at country level to improve the collection and use of statistics.

6. FAO statisticians are involved in developing methods in environmental accounting, and in the development of standards for the classification of land use.[8]

7. The FAO water service is actively involved in UN system-wide water work through its AQUASTAT Programme, which is FAO's global information system on water and agriculture, and in particular has contributed to the development of the International Recommendations on Water Statistics (IRWS) in the Sub-group on (SEEA-Water Statistics (SWS) of the Working Group of Environment Statistics) with UNSD.

8. FAO policy analysts are actively engaged in examining opportunities for Payment for Environmental Services.[9]

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[6] The FAO Land Degradation in Dryland Areas (LADA) programme identifies 132 indicators from aridity to water salinity.

[7] FAOSTAT is available at http://faostat.fao.org/default.aspx

[8] FAO was responsible for the development of the Global AgroEcological Zone (GAEZ) methodology which uses a land resources inventory for specified management conditions and levels of inputs to identify feasible land use options and to quantify expected production.

[9] SOFA (2007)

Box 1: An example of resource monitoring – Global Forest Resources Assessments (FAO, 2010)

FAO has been monitoring the world's forests at 5 to 10 year intervals since 1946. The Global Forest Resources Assessments (FRA) are based on data that countries provide to FAO in response to a common questionnaire. FAO then compiles and analyses the information and presents the current status of the world's forest resources and their changes over time. The scope of the assessments has gradually expanded. The first assessments were focused on wood supply in response to fears of a wood shortage after the Second World War. Today, the assessments have a much wider scope, providing a holistic perspective on global forest resources, their management and uses. By addressing seven broad topics aimed at monitoring progress towards sustainable forest management, the Global Forest Resources Assessments provide valuable information to policy-makers in individual countries, to international negotiations and arrangements related to forests and to the general public.

The seven broad topics, also known as the thematic elements of sustainable forest management, are as follows:

1. Extent of forest resources and their contribution to the global carbon cycle
2. Forest health and vitality
3. Forest biological diversity
4. Productive functions of forests
5. Protective functions of forests
6. Socio-economic functions of forests
7. Legal, policy and institutional framework related to forests

90 variables are currently defined (FRA, 2010), and data collected fom 233 countries from 900 contributors including nominated national correspondents

The Forest Resources Assessments (FRA) show what can be achieved in this area with stakeholder commitment and true national ownership over the long term. However, there may be a material difference between FRA and trying to create similar assessment tools for cropping systems. Given the greater scope for management interventions in cropping systems, the latter would require collection of data on a very broad range of types of pollution and degradation, (inherently a less attractive task!), confirmed by chemical or other analysis.

9. The underlying sustainability issues in the different sub-sectors can be more or less complex. For instance, the sheer range of cropping systems practised in different agro-ecosystems globally - and the diverse nature of the interactions between the various cropping systems and the unmanaged environment - make the definition of relevant environmental statistics for crop production particularly challenging. It is also important to factor-in the environmental impact of post harvest management, primary processing and distribution.

10. Despite the differences in complexity in the different areas, some common themes do emerge. Efforts are made to take an *ecological* perspective in sustainability assessments, with a number of broadly-based indicators reported, whatever the sub-sector.

11. In each of the sub-sectors, assessments may be made at different *scales* based on physical (field, valley, irrigation scheme, watershed) and human/administrative (farm, village, district, province) units. The purpose of making an assessment might be to guide resource management decisions at local scale; to support programme management at district or national scale; or to support policy development (on a local national, regional or global scale, or on a river basin scale).

12. Because of these multiple scales, there is a need to develop tools and indicators for farmers, scientists and policy-makers to monitor, discuss, and plan/negotiate/modify agro-ecosystems at each level. In some cases the data gathered at local level can be summed to produce an aggregate picture, but in other cases the types of information needed at a broader scale are different to those needed at the local scale (discussed further below).

13. It is not enough to design a global system of monitoring where the principal users are developed country scientists, international agencies or conventions, or large NGOs. Monitoring will be successful (with valid data collected), only if there is clear benefit to *local* communities and policy makers. This in turn presents a large task in awareness and capacity development. In many developing countries there is often little tradition of evidence-based policy making, nor are there strong institutions capable of implementing emerging regulations, schemes or programmes designed to foster large scale sustainable behaviour.

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Sustainable Crop Production Intensification and environmental statistics: a user perspective

14. Faced with long run projections of increasing demand for food[10], FAO's Sustainable Crop Production Intensification (SCPI) programme advises Member States on

[10] SOFA, 2009; Schmidhuber 2010; Agriculture Towards 2015/30; and Agriculture Towards 2030/50 (all FAO)

policies and practices to intensify crop production while minimising any negative biophysical or socioeconomic consequences or externalities.[11]

15. In practice, the term "SCPI" covers a number of related concepts, including but not limited to enhanced agricultural productivity; environmentally-friendly crop protection; conservation and use of managed and associated biodiversity; enhancement of ecosystem services; and strengthened livelihoods. Environmental considerations are clearly not the only factor in determining sustainable scenarios. Practices may be environmentally sustainable but might be considered uneconomic (in cases where environmental costs are not borne by producers) or too labour-intensive, or sustainable practices may jar with local traditions or values.

16. This section suggests some possible indicators that could be used to support and monitor both local and national sustainable crop production intensification activities. This principally involves determining (i) whether intensification is taking place and (ii) whether the resulting intensified production systems are sustainable, at both local and wider area scale

- ***'Intensification'*** can be monitored nationally through production statistics, at the simplest level through yield per hectare. A further dimension of intensification is cropping intensity, a measure of the practice of double cropping. The potential to increase cropping intensity at a given location depends on a range of agro-ecological variables (length of growing season, soil or water constraints, etc) – what is important is the extent to which this potential is realised. Further information on the nature of intensification might be obtained by tracking changes in land holding patterns, such as the size of the mean and median land holding in particular production zones, and in the patterns of crop rotation practised. Increasing mechanisation – often associated with intensification – might also be seen in increasing field sizes over time, particularly in smallholder systems, and this might be detectable through remote sensing.

- **'*Sustainable*'** implies persistence, maintained without depleting the resource base irreversibly. Sustainability is not so much an end point as a description of a system in equilibrium. A number of attempts have been made to define principles of sustainability to determine whether crop production intensification is sustainable or not. These can help determine some benchmarks to guide farmers, researchers and policy makers.

17. For the purposes of this paper, we have here selected one recent example (Royal Society, 2009) - which focuses on environmental or biophysical factors in sustainability - as an illustration.

[11] CBD, The Economics of Ecosystems and Biodiversity http://www.teebweb.org/ identifies the main externalities as changes in land-use at the expense of forests and other ecosystems, land degradation and nutrient depletion (Chapter 5). Also, OECD (2008).

Box 2: principles of sustainability

A sustainable production system exhibits most of the following attributes:

1. Utilises crop varieties and livestock breeds with high productivity per externally derived input;

2. Avoids the unnecessary use of external inputs;

3. Harnesses agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy,predation and parasitism;

4. Minimises the use of technologies or practices that have adverse impacts on the environment and human health;

5. Makes productive use of human capital in the form of knowledge and capacity to adapt and innovate and social capital to resolve common landscape-scale problems;

6. Quantifies and minimises the impacts of system management on externalities such as GHG emissions, clean water availability, carbon sequestration, conservation of biodiversity, and dispersal of pests, pathogens and weeds.

[Royal Society, 2009, Reaping the Benefits]

18. Taking such principles in turn, it is possible to define classes of information which would refer to the sustainability of crop production for each of the listed attributes. Such an analysis is clearly just a starting point to facilitate discussion with stakeholders. Ultimately, indicators must be defined and agreed together between the various interested parties locally, nationally, or internationally.

Table 1: assessment of sustainability

Sustainability Principle	**Information needed to assess**	**comments**
1. utilizes crop varieties with high productivity per externally-derived input	• which varieties (improved or traditional) are most highly productive per unit input, for the economically available inputs, under which production systems and what different local conditions (to be researched) • what proportion of particular crops (by MT or ha) are given over to high yielding varieties (survey)	input productivity must be balanced with a consideration of palatability or usefulness from a livelihoods perspective local varieties have a role to play which is not limited to productivity, but which contributes to the diversity and resilience of production systems

Sustainability Principle	Information needed to assess	comments
2. avoids unnecessary use of external inputs	• how much external input is procured, and potentially used in each production zone • how much should be necessary, given prevailing conditions, varieties used, agroecosystem characterization, cropping system • how much over-use is taking place (monitored through proxies such as water quality)	avoiding unnecessary use of inputs and harnessing agro-ecological processes (# 3) are closely inter-related getting data from the private sector on input sales may be difficult local agricultural research might be needed to determine input needs under local conditions
3. harnesses agro-ecological processes	• to what extent are farmers using practices which harness agroecological practices (to be estimated from qualitative surveys of farming practices such as CA, IPM, IPNM, Weed management, etc). Also, quantifiable estimates of - pesticide and herbicide use - area of land under CA vs tillage • validation by spot observation/sampling of biological indicators (such as AESA, PLFA for soil bacteria, species/diversity counts, soil organic matter)	
4. minimizes use of technologies or practices that have adverse impacts on the environment	• assess the extent of sample inherently less sustainable practices: - monoculture - growing crops in zones which are agro-ecologically unsuited to them - excessive or inappropriate tillage - too frequent repeated "slash and burn" practices at a given location - pesticide use • extent of pest, disease, physiological stress	remote sensing may be a means of assessing the use of some of these practices on an area-wide basis, over time Remote sensing
5. makes productive use of human capital and social capacity	• indicators of the level of engagement of farmers in adaptive research • social networks, farmers congresses, farmers' technology juries, etc • evidence of the existence of schemes to encourage local involvement in resource allocation decisions	Farmer/community involvement in adaptation of technology is likely to lead to greater commitment to the use of such technologies

Sustainability Principle	Information needed to assess	comments
6. quantifies and minimizes impact of system management or that increase negative externalities	• measurement and monitoring of actual on farm GHG emissions, water quality, biodiversity, carbon sequestration, etc • sampling and modeling at wider scale • identification of locally appropriate measures to mitigate/minimize	this is closely related to # 2 and # 4

Nature and Scale of Indicators[12]

Nature

19. Reviewing this information, it is possible to define three types - nested levels - of economic, social and environmental indicators that can be recognised to monitor or measure progress in sustainable production systems and sustainable intensification, and impact on economic and social conditions:

- at level one, it is the ***uptake of sustainable practices*** that is being sought (e.g. to monitor progress adopting sustainable production systems and practices based on CA, the indicators would be the specification of the production system, the number of farmers practicing it and the area covered).

- at level two, it is the ***observable impact*** resulting from the change in mindset and practices that is being sought (e.g. yield, income, stability and productivity, as well as ecosystem services such as soil health and quality, soil organic matter, infiltration, soil life (earthworms), erosion/runoff, crop health, specific components of biodiversity such as pollinator bees or natural enemies of pests, etc).

- at the third level, it is the ***outcome*** – the change in the state of the economic, social and environmental conditions of the target group and their area that is being sought (e.g. in the case of the environment, four parameters are important for monitoring progress – state of landscape and soil quality, of biodiversity, of water resources, and climate change mitigation).

Scale

20. Indicators are needed at different scales for use by different groups:

- ***local:*** the use of benchmarks in pilot and other activities to develop and adapt technologies, and to test the guidance being given. Some of these benchmarks are

[12] Prof A. Kassam contributed significantly to this section.

for use at the ‘micro’ scale – sustainable intensification depends on the locality-specific decisions of farmers which cannot be easily seen in more aggregated measures.

- ***aggregate:*** the use of ‘macro’ indicators needed by policy makers at larger scale. These would include status and trends at regional and national level in soil fertility, water usage (at river basin scale), pesticide consumption and the levels of adoption of effective technologies appropriate to sustainable intensification.

Local: the assessment, validation and adaptation and monitoring of new technologies

21. Prior to adoption, new technologies (or packages of technologies, approaches) need to be assessed under ***local*** conditions to determine whether they are sustainable in a particular ecosystem/at a particular locality. This is not new – it essentially describes a partnership between farmers, extension workers and local agricultural research institutions and NGOs, as practised for many years. What is new is the range of more or less complex tests and diagnostic methods which are now available to support this process of assessment and adaptation.

22. Farmers are often the best informed about local conditions and practices, what works and what doesn't. When something new (a technique, a variety, etc) becomes available, the farmers usually take some time to assess and evaluate based on their own resources, and their own evaluation of potential risks.

23. This process can be facilitated by use of participatory techniques such as farmer field schools - used by local extension, services, agricultural research or NGOs – to support assessment and adaptation. Here, farmers may be testing, adapting or adopting new techniques of composting, mulching, reduced or no tillage, use of cover crops, integrated weed and/or pest management. The field school may also include primary processing, or other value addition, business and marketing. Field work typically takes place on shared study plots, and farmers compare conventional and novel practices, measuring the impact in terms of output and simple local sustainability indicators.

24. In helping farmers to determine which approaches to adapt and then adopt, field schools encourage farmers to use robust and reliable approaches to quantify the impact of the different measures in real time, usually over a growing season. They can use, for instance, leaf colour charts for plant nutrition, dipsticks for chemical properties of soil, direct field observation of pest and natural enemy populations, identifying and 'rogueing' of diseased plants, etc. In many cases, farmer field school alumni continue to use their skills of observation with these simple techniques long after the successful conclusion of the field school, and are left with a heightened appreciation of sustainability issues.

25. Taking a practical example, soil fertility under intensification depends on the levels of available Nitrogen (N) which might be the result of the addition of mineral fertiliser, the biological fixation of N, atmospheric deposition, etc.

26. But in practice, fertiliser may be broadcast, dosed to particular plants or even deep-placed in the case of rice (IFDC, 2006); timing of application may also be important, while a full assessment of the right amount of fertiliser to be added could consider levels of soil organic matter or other available nutrients; and indicators of soil health such as species diversity (flora and fauna), including earthworms, nematodes and

fungi; or presence of soil bacteria. Other objectively measurable or observable indicators of soil characteristics affected by intensification include soil structure and depth, salinity or acidity. These are also influenced by management practice, and can be studied when considering how to intensify production sustainably.

27. In addition to soil health and fertility, the ecological sustainability of crop production intensification is also determined by:

- sustainability of water resource use based on the water cycle (surface water resources, level of water table, etc) and water quality (presence of residues of agrochemicals, eutrophication, sedimentation)
- cropping diversity – indicators of monoculture versus mixed cropping; within one crop, use of locally adapted varieties and landraces (for the impact on resilience in the presence of pests and disease, and local stresses like drought, flood, wind, air pollution; availability of locally-relevant plant genetic resources); use of crop rotations; intercropping, etc
- farm power - use of renewables (local biofuel such as biodiesel; solar energy for drying; use of draught animals[13]); minimising use of non-renewable energy sources
- net emissions and/or carbon sequestration associated with different farming practices in the context of mitigation of climate change
- indicators of impact of farming on other environmental indicators in adjacent ecosystems (natural pollinator populations, wild birds, species diversity) through reduced water quality, pesticide aerial drift, etc
- ecological bases of local weed and pest management

28. Again, these represent possible material for field study, and practices need to be considered for their full impact on a broader range of ecosystem services. A practice with a positive impact on soil N, may also have an impact (positive or negative) on water use efficiency, or pest and disease control (soil borne pathogens), or weed management. Also, practices may be blended, or adopted partially to suit local conditions. .

29. Taking a known technology or practice (such as CA, IPM, IPNM or drip irrigation), applying it at a particular location, and adapting it to local conditions can be seen as a form of adaptive research. In this local research institutions have a role to play, but in all of this farmers are key.

Aggregate: assessment for policy makers at larger scale

30. The kinds of sustainability questions to be answered at a larger scale – watershed or river basin, national, regional – and over a longer time horizon - do not just concern

[13] although with draught animals, feed, waste and GHG emissions may be factors in whether their use is truly renewable or not.

the suitability of specific technologies or the ways in which they are being adopted by local farmers. The broader questions are posed by policy makers who are looking to support the more widespread adoption of sustainable practices while encouraging intensification and development of rural livelihoods, and the support of national food security. As well as ecological concerns over the long term viability of production, policy makers need to explore and then understand the influence of prices and subsidies, trade, long term development scenarios, etc.

31. If policy makers need to understand how sustainable is agriculture in the ***aggregate***, the scale of study might include production system (eg CA, tillage agriculture, etc), cropping system (for instance "cereal-root crop mixed"), river basin (the Nile basin), and/or the various levels of administrative unit (district, province, region, etc).[14]

32. At the highest level of generalisation policy makers need to answer questions such as - which land should be used for agriculture (and how intensively); which should be protected for conservation purposes?

33. At a more specific level the questions might be:

- what are yields for the various crops, by area, what is the yield gap (against an agreed reference value), and what is the range of yields actually being achieved?
- what soil fertility problems are known in a given district or province?
- what are the trends of input use (seed of improved varieties, fertiliser, pesticide) in particular regions (use, price, availability), including distinction between those which are irrigated and those which are rain-fed?
- which are the areas of the country with water quality problems?
- which are the areas of the country with water quantity problems?
- are particular crops being grown in places where water is not consistently available?
- how close to eventual consumers are products being grown, in terms of time and distance?
- what is the degree of mechanisation, and with what energy and GHG footprint?

34. The kinds of support that policy makers can bring include:

- ***providing advisory services*****:** capacity development (many of the combinations of SCPI technology are "knowledge-intensive" and some form of technical assistance and follow-up networking is usually needed by farmers to access these);
- ***creating incentives:*** targeted subsidies for particular inputs and practices (or removal of perverse subsidies in the case of over- or mis-use of inputs like pesticides) – these may be temporary measures to encourage sustainable approaches; the government procurement to support local producers and shorten

[14] For Farming Systems see Dixon et al, (FAO/WB, 2001); also MEA, 2005)

food supply chains; tax and other incentives for particular forms of enterprise development, procurement of equipment, etc;

- ***supporting long-term investments:*** ecosystem deterioration, and conversely improvement/rehabilitation is a long term process – credit schemes for long term investments which would otherwise be beyond small, resource-poor farmers are an essential component;
- ***enhancing coordination:*** ecosystem management requires collective actionand coordination between different land users.[15]

35. But in order to do this, policy makers need to understand the current environmental impact of agricultural production, and assess the potential outcome of their policy measures if implemented. This requires the development of scenarios and models... which requires the definition of relationships, and real or estimated data.[16]

36. One problem is that for many of the variables which can be monitored directly it is not easy to infer conclusions about a wider area, or to draw more general conclusions on sustainability. For instance, an observation on soil at one point location may (or may not) be representative of the rest of the field, of the farm, or the rest of the village, or the rest of the valley.

37. What would help policy makers draw more general conclusions would be variables which relate to the *collective* practice of agriculture. First and foremost among these is water quality. Because water moves through the land and carries with it soil, nutrients and pollutants, it integrates some of the most important elements of agricultural production across larger spatial scales.

38. For example, from an analysis of water quality in streams and rivers in agricultural areas, it can be possible to determine the pattern of use of fertiliser in a particular catchment area, through detection of nitrates and phosphates in run off. Also, the level of agrochemical (pesticide) use can be seen in the detection of residues. A third indicator from water would be the level of sediment in the water flow, which is an indicator of the loss of topsoil.[17] Further indicators could include salinity or acidity. The significance of a single observation is limited but the aim is to monitor changes over time. Technologies are becoming available for such cumulative monitoring, in some cases based on membranes and advanced analytical techniques.

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[15] Derived from TEEB (2010)

[16] See for instance the four principal scenarios of the Millenium Assessment (Controlled, Mosaic, Technology Gardens, etc)

[17] examples of this type of analysis see BM Swallow et al "Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa" in Environmental Science and Policy 12/4, pp 504-519, (2009)

39. Monitoring water resources on a catchment area basis is also useful to determine whether water resources are being depleted as a result of farming activities. Here, both river discharges and levels of ground water can be monitored, again over time, to determine whether extractions, principally for agricultural purposes, are having an impact.

40. Other measures which may be used as a proxy for ecosystem health could be the populations and/or diversity of pollinators or wild birds. The characteristic which these "area indicators" (water, pollinator, birds) all share is that they move through agro-ecosystems, effectively sampling over a large area. Where the agro-ecosystem is degraded or being used in an unsustainable manner this leaves a trace, in reduced population, diversity or water quality.

41. Some area-wide conclusions may also be drawn from observation, using techniques such as remote sensing. Satellite imagery can provide evidence of changing patterns of land-use over time which would be prohibitively expensive to gather on the ground. Telemetry (observation of sensors at distance) may also have a role.

42. Other broad aggregate measures may be calculated. These are based on assumptions and again can be tracked over time to determine any changes in farming practice and resource usage.

43. For instance, one way of drawing larger scale conclusions on sustainability and plant nutrition would be calculation of gross nutrient balances, like those produced at national level by the OECD, and used for international comparisons.[18]

44. Another example - trends in energy use in agriculture - may be deduced from data on extent of mechanisation and farm power use, fuel consumption, and calculations of energy costs of distribution of produce given particular marketing practices.

45. Matching the calculations on input use, there is need to monitor aggregate figures of farming "outcomes" such as relative yields, income and value addition, etc. This should be taken in the more general context of rural livelihoods, including farm and non-farm income – sustainable farming and more limited intensification may be more feasible where there are other non-farm sources of income.

46. In addition to the ecological and economic data suggested, other aggregate factors in sustainability to consider include population growth, distance between production, primary processing and markets.

Summary/conclusions

[18] Publications such as OECD (2008), *Environmental Performance of Agriculture in OECD countries since 1990*. Also, report of the workshop on agri-environmental indicators (OECD, 2010) http://www.oecd.org/dataoecd/10/44/45449155.pdf

The following are some of the main conclusions from this paper:

- the work of harmonising environmental statistics is a public good
- the revision of FDES provides an opportunity to harmonise the definition of terms and approaches in collecting environmental statistics relevant to the sustainability of crop production
- there is a need to develop and implement monitoring tools appropriate at the different spatial scales
- at local scale, indicators should be developed and agreed as part of a local community-owned process, in the context of community-based education initiatives
- at an aggregate level, a new set of collective indicators of crop production sustainability are needed, given advances in data gathering and modelling, which "sample" agro-ecosystems
- there is a need to establish at national level databases of baseline estimates of key aggregate indicators linked to digital maps of key production areas (sustainability is implicitly about change over time, so in the absence of baselines we are unable to detect change, or monitor movement towards/away from sustainable trends)
- investment is needed to initiate this work beginning with gathering together the disparate, disaggregated knowledge/data which already exist
- there is a need to develop frameworks that move beyond the current disarray of development initiatives to more explicitly-built multi-scalar understanding of status and trends, in the main biophysical and socioeconomic indicators of the sustainability of crop production intensification