OPINION

LEFT TO RIGHT: G. STEINMETZ/CORBIS; A. DE LOSSY AND M. D. DE LOSSY/CULTURA/CORBIS

Monitoring the world's agriculture

To feed the world without further damaging the planet, **Jeffrey Sachs** and 24 food-system experts call for a global data collection and dissemination network to track the myriad impacts of different farming practices.

Agriculture must be transformed. Although global food production is increasing, today's farming systems undermine the well-being of communities in many ways. For instance, farming has destroyed huge regions of natural habitat and caused an untold loss of ecosystem services, and it is responsible for about 30% of greenhouse-gas emissions[1,2]. Already, about 1 billion people are undernourished. Yet to feed the global population expected by 2050, more than 1 billion hectares of wild land will need to be converted to farmland if current approaches continue to be used[3].

SUMMARY

- Agriculture is assessed at different scales, using inconsistent methods and narrow criteria
- A common set of metrics must be collected at comparable scales
- The resultant, freely available data should inform farming practices worldwide

A key step towards making agriculture sustainable is evaluating the effects of different farming systems around the world. Historically, agricultural strategies have been assessed on the basis of a narrow range of criteria, such as profitability or yields. In the future, the monitoring of agricultural systems should address environmental sustainability, food security (people's access to food and the quality of that food), human health, and economic and social well-being.

We propose establishing a global network to monitor the effects of agriculture on the environment, across major ecological and climatic zones, worldwide. This would involve stakeholders — policy-makers, farmers, consumers, corporations, non-governmental organizations, and research and educational institutions — coming together to develop a set of metrics that quantify the social, economic and environmental outcomes of various agricultural strategies. A network of monitoring organizations would then collect the appropriate information, and the resultant, freely available data could inform agricultural management, policy and research priorities.

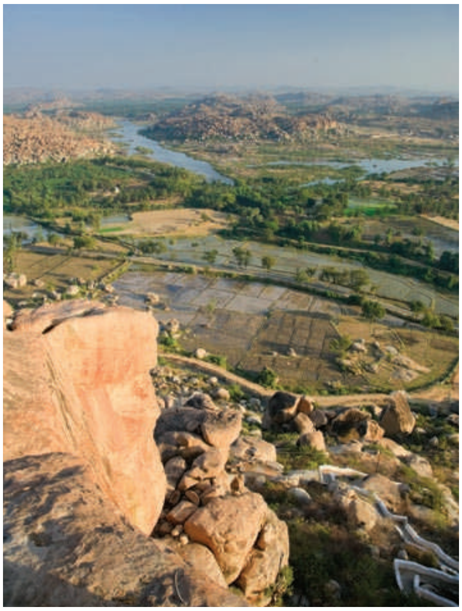
Comparing apples and oranges

The current monitoring of agricultural systems captures only certain effects of farming, by focusing on narrow criteria. Several examples illustrate the need to monitor multiple variables. In the United States, recent investment in the biofuel ethanol has reduced imports of petroleum[4]. But it has also required expensive subsidies, reduced supplies of food and feed grains, spurred deforestation in other regions and perhaps even increased greenhouse-gas emissions overall[5].

Similarly, many consumers, farmers and policy-makers praise organic farming as an ecologically friendly system, but they should consider the additional land and livestock needed to produce 'green manures', the economic cost of producing food in this way and the net effect on greenhouse-gas emissions[6]. In addition, farming genetically modified crops is widely thought to entail certain risks, but these should be assessed alongside the potential benefits, such as reduced pesticide use and higher crop yields[7,8].

A further problem with the current system is that the data collected are rarely comparable across ecological zones because of inconsistencies in methodologies or in the spatial scale at which observations are made[1,2,9]. Agronomists, for example, tend to measure yields from fields that generally range from less than 1 hectare to 200 hectares, whereas landscape ecologists may monitor the way habitats are interconnected over geographical areas of many thousands of hectares. Moreover, some farming systems, such as traditional pastoralist systems, are often under-represented in monitoring efforts[10,11].

To facilitate cross-site comparisons and global modelling, data should be collected for



CLOCKWISE FROM BOTTOM LEFT: S. DAS/PANOS; Y. ARTHUS-BERTRAND/CORBIS; M. FALZONE/JAI/CORBIS; G. GERSTER/PANOS

a suite of metrics in a systematic way, using a common protocol. These metrics should address food security, agricultural yields, farm profitability, soil conservation, greenhouse-gas emissions, local water quality and water use per production unit (tonnes of crop produced per hectare, for example).

In addition to globally applicable metrics, metrics for specific farming systems are needed (see 'Costs and benefits of farming practices'). For example, to understand the energy efficiency of US industrial farms, fossil-fuel and electricity consumption could be measured, whereas for smallholder farmers in rural Africa, energy use in the form of human labour and animal traction might be more relevant.

Joint effort

An international, interdisciplinary meeting was held in October last year to begin developing these metrics and the global network[12]. As a group, the participants, including the authors of this article, are reaching out to leaders of existing agricultural assessment projects, as well as policy-makers, farmers and other stakeholders, to encourage them to take part in the development, selection and measurement of key metrics. We anticipate the development of these metrics to be a participatory and iterative process to ensure consensus and to build demand for the data.

Our examination of 18 diverse monitoring networks — including the Tropical Ecology Assessment & Monitoring Network, and the Earth System Science Partnership global change programme — indicates that roughly 800 monitoring sites across all continents except for Antarctica could be connected[13]. Others from the private sector could be added. Ideally, an online infrastructure, such as the Center for International Earth Science Information Network at the Earth Institute, at Columbia University in New York, would help users to access, understand and apply the data.

The selected metrics would need to be monitored systematically at the appropriate scale. 'Agro-ecological' zones are areas in which the climate, soil type and crops grown are similar. The network we propose here would monitor 'landscapes' within these zones — geographical areas that are defined by common ecological or social characteristics. For instance, a landscape could be demarcated by a village boundary or the limits of a watershed.

COSTS AND BENEFITS OF FARMING PRACTICES

Some examples of metrics that would apply worldwide and others that need to be tailored to local environments and specific agricultural approaches.

Metrics	Food security	Human health	Economic prosperity	Environmental sustainability	Sociocultural well-being
Universal	Calories per person	Micronutrient deficiencies	Employment rate	Greenhouse-gas emissions per production unit	Percentage of children in school
System specific	Food access	Exposure to agrochemicals	Fluctuations in prices of agricultural products	Energy, nutrient and water-use efficiency and input–output balance	Local ecological knowledge

The number of landscape-monitoring sites within an agro-ecological zone would vary depending on the zone's size. For example, the US corn belt (about 100 million hectares) might be assessed at three sites, whereas the sugar-cane production area in Brazil (about 10 million hectares) might need only one monitoring site.

Obtaining data at the landscape scale is crucial for identifying interactions among biophysical factors, such as soil erosion and water quality, and socio-economic factors, such as human health, social well-being and income, over the short term (a few growing seasons) and the long term (decades)[10]. Such data would also provide a bridge between farm-level data and national, regional or global monitoring efforts, and they would allow comparisons across scales (see 'A holistic view'). Local findings — on yields or profitability, for instance — would help network users to define better parameters for models at the landscape level and to validate these models.

Several multiscale, interdisciplinary monitoring efforts have developed the kinds of methods, and collect the types of data, that would be suitable for the global network proposed here. The Africa Soil Information Service, or AfSIS (http://africasoils.net), for instance, is the African node of a new global soil-mapping network that is supported by a working group of the International Union of Soil Sciences.

AfSIS is mapping soil and ecosystem conditions in sub-Saharan Africa by systematically sampling sentinel sites to ensure that adequate data are collected for the major climatic zones, as well as by combining multivariate modelling, infrared spectroscopy and remote sensing. In this way, AfSIS is establishing a baseline for monitoring changes. It is also providing

A HOLISTIC VIEW

Metrics monitored at the level of a village or watershed (at the landscape scale) can be integrated with data collected from individual farms, as well as regions, nations and continents. This will inform local and global models, help researchers to make cross-site comparisons and lead to evidence-based food policy.

LEFT TO RIGHT: A. AITCHISON/IN PICTURES/CORBIS; Y. ARTHUS-BERTRAND/CORBIS; NASA

policy-makers, scientists, land managers and farmers with options for improving soil and land management in the region.

The Millennium Villages project (www.millenniumvillages.org) — which supports rural African communities to help overcome extreme poverty — demonstrates the use of biophysical and socio-economic data to track progress in sustainable development. Likewise, the Millennium Ecosystem Assessment's sub-global assessments (www.millenniumassessment.org/en/multiscale.aspx) — which look at the intersection between poverty and ecology — have illustrated how to link information from farmers' fields to global trends by using local and national data sources and global models.

Getting started

The new global monitoring network would build on the experience and expertise of existing efforts, while differing from current networks and international research programmes in several major ways.

Although agriculture is arguably one of the most important ecological systems in the world, most long-term ecological-monitoring networks have focused on natural ecosystems[12,13]. Of the current projects that assess agriculture, some track food security, economic well-being and various environmental impacts, but few focus on human health, social and cultural outcomes or a comprehensive range of environmental impacts. And none monitors all of these simultaneously[12].

Major international agricultural institutions such as the Consultative Group on International Agricultural Research (CGIAR) and the Food and Agriculture Organization of the United Nations are moving towards multidisciplinary teams and using more inclusive metrics. The global monitoring network that we are proposing would provide a knowledge base to support the necessary long-term changes at large international institutions.

To build on the diverse existing monitoring efforts, we would encourage a highly decentralized research structure, supported by a central hub for data management. This structure would be similar to that of the Human Genome Project — in which hundreds of scientists at dozens of sequencing centres worldwide harmonized their work while maintaining their independence and specialized focus.

Setting up the monitoring network would entail three major activities. A steering group of scientists and other stakeholders would reach consensus on the key metrics, a process that we estimate would require about US$500,000 and take 1 year to complete. The steering group would then design and build the project's cyber-infrastructure, database management and training platform, requiring an initial investment of perhaps $10 million, and $1 million per year thereafter. Finally, site monitoring would begin when the programme's metrics have been defined and the infrastructure is in place. We expect the costs of monitoring to vary widely by site, the price at a typical site being estimated at $200,000–300,000 per year.

Many scientific disciplines are showing increasing interest in agriculture. This will ensure the scientific capacity to guide this multidimensional effort. Furthermore, the recent global resurgence of funding for agricultural development — exemplified by the $20 billion that was committed to smallholder agriculture in low-income countries by the Group of Eight (G8) nations in July 2009 — should help finance the network. Donors from the public, voluntary and private sectors will be approached to support the effort.

Making the transition to healthy, equitable and sustainable agriculture is a daunting challenge. To succeed, we will need to track and understand the diverse and changing impact of farming practices. The global monitoring network that we propose could be in place by mid-2012. And by 2015, the new data would support a much richer understanding of global agriculture and the path to agricultural sustainability. ■

Jeffrey Sachs is director of the Earth Institute at Columbia University and special adviser to UN secretary-general Ban Ki-moon. **Roseline Remans** is at the Earth Institute, Columbia University, and Leuven Sustainable Earth, Katholieke Universiteit Leuven. **Sean Smukler** is at the Earth Institute, Columbia University. **Leigh Winowiecki** is at the Earth Institute, Columbia University. **Sandy J. Andelman** is at Tropical Ecology Assessment & Monitoring Network, Conservation International. **Kenneth G. Cassman** is in the Department of Agronomy and Horticulture, University of Nebraska–Lincoln. **David Castle** is in the Faculty of Arts and Faculty of Law, University of Ottawa. **Ruth DeFries** is in the Department of Ecology, Evolution, and Environmental Biology, Columbia University. **Glenn Denning** is at the School of International and Public Affairs, Columbia University. **Jessica Fanzo** is at Bioversity International, Rome, Italy. **Louise E. Jackson** is in the Department of Land, Air and Water Resources, University of California, Davis. **Rik Leemans** is in the Environmental System Analysis Group, Wageningen University. **Johannes Lehmann** is in the Department of Crop and Soil Sciences, Cornell University. **Jeffrey C. Milder** is at EcoAgriculture Partners, Washington DC. **Shahid Naeem** is in the Department of Ecology, Evolution, and Environmental Biology, Columbia University. **Generose Nziguheba** is at the Earth Institute, Columbia University. **Cheryl A. Palm** is at the Earth Institute, Columbia University. **Prabhu L. Pingali** is at the Bill & Melinda Gates Foundation, Seattle, Washington. **John P. Reganold** is in the Department of Crop and Soil Sciences, Washington State University. **Daniel D. Richter** is in the Environmental Sciences and Policy Division, Nicholas School of the Environment, Duke University. **Sara J. Scherr** is at EcoAgriculture Partners. **Jason Sircely** is in the Department of Ecology, Evolution, and Environmental Biology, Columbia University. **Clare Sullivan** is at the Earth Institute, Columbia University. **Thomas P. Tomich** is at the Agricultural Sustainability Institute, University of California, Davis. **Pedro A. Sanchez** is at the Earth Institute, Columbia University.

1. Intergovernmental Panel on Climate Change. *Fourth Assessment Report: Climate Change 2007* (Cambridge Univ. Press, 2007).
2. Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: Synthesis* (Island Press, 2005).
3. Tilman, D. *et al. Science* **292,** 281–284 (2001).
4. http://www.ethanolrfa.org/pages/statistics
5. Tilman, D. *et al. Science* **325,** 270–271 (2009).
6. Green, R. E., Cornell, S. J., Scharlemann, J. P. W. & Balmford, A. *Science* **307,** 550–555 (2005).
7. Lemaux, P. G. *Annu. Rev. Plant Biol.* **59,** 771–812 (2008).
8. Lemaux, P. G. *Annu. Rev. Plant Biol.* **60,** 511–559 (2009).
9. International Assessment of Agricultural Knowledge, Science and Technology for Development. *Agriculture at a Crossroads: Global Report* (Island Press, 2009).
10. Jackson, L., Bawa, K., Pascual, U. & Perrings, C. *agroBIODIVERSITY: A New Science Agenda for Biodiversity in Support of Sustainable Agroecosystems* (DIVERSITAS, 2005).
11. Sachs, J. D. *et al. Science* **325,** 1502–1503 (2009).
12. http://www.tropag.ei.columbia.edu/?id=global_agriculture
13. http://www.tropag.ei.columbia.edu/?id=research_global_metrics_agriculture

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