Meeting farmers' needs for agrometeorological services: A review with case studies part II: Context 1, the existing situation

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Meeting farmers' needs for agrometeorological services: an overview and case studies

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Abstract

Meeting the needs for agrometeorological services, including agroclimatological services, in the livelihood of farmers is the focus of this paper. Some historical aspects are dealt with in the introduction, particularly regarding the definition and scope of agrometeorology. What has recently been said about such services is quoted, including example from Cuba and South Africa. Much was already reported by us on the context of farmers' needs for agrometeorological services. We therefore use now some recent reviews of this context in which we recognize that of our own approaches. These reviews deal with the existing situation in Africa, Asia and Latin America from angles of water/fertility/markets (Africa), traditional, conventional/intensive and organic farming (Asia) and operational frameworks that provide agrometeorological information to farmers, extension services and other stakeholders with some emphasis on internet information (Latin America). Examples from Australia, India and South Africa strengthen the arguments. The future is subsequently dealt with from the point of view of agroforestry and communication in agrometeorology as connecting principles for these reviews. Targeted capacity building initiatives are an essential component of the communication process. Farmer/Climate Field Schools appear to have large potentials here. These are the ultimate new educational commitments with which new agrometeorological services are established. While in these participative approaches the understanding of farmers' needs can be extended and used to redress and improve the existing situations earlier described, using these agrometeorological services. The remainder of the paper deals with case studies to illustrate some best examples of agrometeorological services.

Introduction

History

In the past 40 years, the fields where agricultural meteorology is applied grew extensively (WMO, 2006). With an increasing rate of application in the developing world, the definition of agricultural meteorology had to be widened to accommodate the conditions in developing countries, with their more abundant weather and climate disasters and their endangered environments. This was the first gradual widening of priorities in agricultural meteorology (Stigter, 2008; 2009a).

In his Roving Seminars and elsewhere, Stigter teaches that society and economics do not equate to agricultural meteorology, but that the consequences and use (that is, management) of water, radiation/heat and air in society and economics, as far as the agricultural production environment is concerned, slowly became an undercurrent in agricultural meteorology (WMO, 2006; KNMI, 2009). Translated to poorer countries, the socio-economic aspects of elements such as multiple cropping, irrigation, storage, agroforestry, floods, drought, erosion and desertification, frost and wind protection, simple artificial growth conditions, sustainable farming and related farmers' income generation became additional priorities in that widening undercurrent of agricultural meteorology. This was a second gradual widening of the subjects associated with agricultural meteorology (Stigter, 2008; 2009a).

The widening of the definition of agricultural meteorology and the second widening of the scope of related subjects have largely been missed by training and education, and more so in developing countries (Stigter, 2009a). This can be explained through a simple conceptual and diagnostic framework that was most recently published in a guest editorial (Stigter, 2007) and is also used in Stigter (2009a; 2010a) and Stigter et al. (2010).

By this new definition (as worded by Stigter and Walker in a 2008 folder of the University of the Free State (UFS), Bloemfontein, South Africa), agrometeorology and agroclimatology investigate adaptation strategies to weather and climate in raising crops, trees, livestock and fish. They study water, heat, air and related biomass development in the agricultural production environment, including disasters, and their socio-economic consequences for farmers as decision makers. This ideally leads to agrometeorological services for response farming with irrigation scheduling, early warnings, microclimate manipulation, and application of weather and climate forecasts in a changing and increasingly variable climate (Stigter and Walker in the same 2008 UFS folder).

Meeting the needs for agrometeorological services, including agroclimatological services, in the livelihood of farmers is the focus of this paper. Such services were defined, exemplified and explained in Stigter (2007a) (List I).

List I. Agrometeorological services as defined in Stigter (2007a)

- The products of agroclimatological characterization, obtained with whatever methodologies;
- Advises such as in design rules on above and below ground microclimate management or manipulation, with respect to any appreciable microclimatic improvement: shading, wind protection, mulching, other surface modification, drying, storage, frost protection, etc.;
- Advisories based on the outcome of response farming exercises, from sowing window to harvesting time, using climatic variability data & statistics of a recent past or simple on-line agrometeorological information;
- Establishing measures reducing the impacts and mitigating the consequences of weather and climate related natural disasters for agricultural production;
- Monitoring and early warning exercises directly connected to such already established measures in agricultural production, to reduce the impacts and to mitigate the consequences of weather and climate related natural disasters for agricultural production;
- Climate predictions and forecasts and meteorological forecasts for agriculture and related activities, on a variety of time scales, from years to seasons and weeks, and from a variety of sources;
- Development and validation of adaptation strategies to increasing climate variability and climate change and other changing conditions in the physical, social and economic environments of the livelihood of farmers;
- Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases and/or advises on countervailing measures;
- Advices on measures reducing the contributions of agricultural production to global warming and keeping an optimum level of non-degraded land dedicated to agricultural production;
- Proposing means of direct agrometeorological assistance to management of natural resources for development of sustainable farming systems in technological advances with strong agrometeorological components.

Stigter therefore also teaches in his Roving Seminars that next to “science and technology” and ”the understanding of local adaptive strategies and innovations”, the four cornerstones of what is needed to fight poverty, empower people and enhance people’s dignity through life long education, are completed by agrometeorological services as “policies” and ”the high internal input”: the farmers themselves (KNMI, 2009)!

Agrometeorological services

Agrometeorological services in developing countries have to shoulder greater responsibilities due to larger population pressure and changing modes of agricultural practices. More and more demands pertaining to agrometeorological information and services will be coming from the farming communities in the future, on technologies, farming systems patterns and practices (better including multiple cropping, see Stigter, 2010a), water management, weather based pest and disease control etc., preferably with local innovations as starting points. Thus the future challenges include the necessity to emphasize a bottom up approach so that forecasts, specific advisories and contingency planning serve even the small farmers for applications in their planning and day-to-day agricultural operations (Stigter et al., 2010). See for understanding the actual problems in developing countries the Cuban example of Box 1 and for an example of a solution developed in Zambia Box II.

Box I. Cuban experience in the communication of local agrometeorological information and services

Transfer of agrometeorological information to farmers is done in different ways. Meteorological Services use different options, such as periodical bulletins (printed or web), mass media: TV, radio or newspapers and/or e–mails. Perception studies developed in areas around an agrometeorological station in Villa Clara[i], central region of Cuba, showed that meteorological information was useful to most of the farmers. However, a considerable portion of the farmers was unaware of the concepts and scope of agricultural meteorology.

Moreover, it was found that the national television news (NTV) and/or national radio stations were selected more often as the first source of weather information, followed by the local television channel (TELECUBANACÁN) and/or local radio. Respondents to this questionnaire, all of them farmers, this way always kept themselves informed on the weather situation and used that information mostly for planning purposes. What can we do to improve on that situation? How to convey more specific agrometeorological information safely and understandably to producers? To solve this problem, our conditions demand to make a differentiation, because obviously messages aimed at managers of agricultural enterprises differ from those whose receptors are individual producers. In Cuba these actors generally do not have access to electronic networks and in many cases even lack telephones, to mention two elements considered limitations for the design or establishment of any information system.

First, in the case of agricultural managers, the agrometeorological services should be simple for their proper assimilation and they must be used frequently to facilitate decision-making and planning. The experience with communication of local agrometeorological information showed that e-mail can be a good choice, but this has some essential limitations such as: i) customer should be a user of an e-mail provider: This prerequisite is not always met; ii) excessive personalization of information: the information reaches only the recipient, without opportunity for all others interested to get documented, iii) additional costs for information transport, depending on the connection fee of the company to his mail provider, iv) limited operation: arrival of the information at its destination depends on the connection between transmission and reception and v) improper delegation of responsibility: part of the responsibility for the speed and quality of information would depend on third parties.

These considerations led to the creation of a system for information transport, the so called *Remote Web System*, which was established on the basis of a link *point to point* (P2P), which has certain technical advantages, including: i) updating is independent of user intervention, ii) provides a framework for the review of information, iii) allows for secure information exchange between supplier and customer and iv) the supplier has all the statistical use and it is easy to determine any violation of the regulations. *Remote Web System* contributed to the solution, but only partially because lack of telephone lines and modems capable to cover all customers in a minimum of time, was, next to website design (requires a more “flexible” website) and training, the most important constraint. The problem for individual farmers remains because we aimed at farm managers. Certainly, we are not satisfied! What to do?

It imposes the need to “downscale” the role of agrometeorological stations, which should not only be "centers for collecting data and information" but also something like a referral and consultation center at the local level. If we take a look at our surface weather stations, it should be closest to the agricultural producers. It somehow should reach those places we can not "see" and have the badly wanted possibility to be in direct contact with farmers. Daily we witness that data and agrometeorological information "are lost" without use of their potentials. The idea then arose to use the local radio transmitters as spokesmen of our message. Of course, to reach this goal, the first step was negotiating with the broadcasting authorities to obtain time blocks - in our case free of charge – at times that farmers can listen. At the same time we designed and distributed a new monthly agrometeorological newsletter. Radio ensures greater “visibility” of the agrometeorological information, but how do farmers absorb this information? Do they know how to interpret it? Does it meet their needs? To answer these questions requires evaluation of receipt and use of these services, increasingly focused on the local farmers. In this process, agrometeorologists should be assisted by social communication specialists to ensure the success of their endeavours with the right differentiation (see also Stigter et al., 2007).

[i]Further information on this study can be found at http://ram.meteored.com/numero46/informacion-agrometeorologica.asp (only in Spanish).

Box II. Use of local community radio to distribute seasonal farmer advice in Zambia

The farmers in the Mujika area requested further information about the climate and how it affects their crops. Through participatory needs assessments at several villages in the area, it was established that there are a range of on-farm decisions that are dependent on the environment. For example, they have a range of lands available for cropping from clay soils in low lying areas to sandy soils in the higher areas. There are also a range of maize seeds available of different growing period length for short, medium and long season varieties. Each year the farmers must decide which seed to plant; as well as where and when to plant them. The existing local community radio station in Monze agreed that the Agrometeorologist can broadcast farmer-climate information in a regular slot once a week. Some of the broadcasts took the form of a role play with several people who discuss the climate messages and their farm activities according to the appropriate time of the year. For instance, before the summer rains begin, the role players discuss the tasks needed to prepare for the maize planting and how the latest seasonal forecast influences their cropping decisions.

The policy support for these agrometeorological services came from the provincial government level from the Southern Province branch of the Department of Meteorology in Livingstone. They were able to supply some tape recorders to some of the farmer study group leaders who then recorded the radio programme each week. Later, these recorded radio programmes were the replayed during the farmer group meetings. The farmers then discussed the information and used the seasonal/climate forecasts to make a decision about which maize variety to plant and where to plant it. The Southern Province Department of Meteorology also supported the personnel to make the radio programmes and to visit some of the farmer meetings. The Meteorology Department made it their policy to support this type of information dissemination to grassroots level in the community (Nanja, 2010)..

Agrometeorological services in developed countries focus on the provision of environmental data and information to national policy and decision makers. They do that in support of sustained food production, sustainable development, carbon sequestration in agro-ecosystems and land management practices that affect exchange processes of greenhouse gasses. Because developed countries may have or develop technology to initially adapt more readily to climate change and climate variability, technology transfer may play a certain role but local innovations, such as those in multiple cropping, remain most important for application under the very different conditions in developing countries (Stigter et al., 2010).

A good definition of livelihood, from Chambers (1990), is: “means to gain adequate stocks and flows of food and cash to meet basic needs, together with reserves and assets to offset risks, ease shocks, and meet contingencies”. The same source argued that in practice the livelihood strategies of poor people, including resource-poor farmers, are often complex and diverse and can be different in the same village (Chambers, 1990). Stigter et al. (2007) showed that four different income-levels of farmers in China treated the technological and related information differently, and their levels of satisfaction were different too. They also appeared to receive the information largely through different channels.

Because operational agrometeorology has to be carried out in the livelihood of farmers, we must be on speaking terms with extensionists, anthropologists, and other agricultural and social scientists as well as development economists (Stigter, 2010a). The bridge between our fields of work and theirs was very well set up by Robert Chambers in his “Microenvironments Unobserved” (Chambers, 1990). His approach explains why scientists, if at all interested in applications of their findings, often come up with wrong solutions presented along the wrong communication channels, and for the exceptional potentially suitable answers in ways that are insufficiently client friendly. He explained then, and Stigter (2010a) repeated this with new arguments, that the consequences of poverty and vulnerability are not clearly understood by scientists, nor are the possibilities within farmers’ actual existence. Indian experience with the latter is found in Box III.

Box III. Experience with agrometeorological services from India

Recent studies in India showed that economic impact of an Agro-Advisory Service (AAS) based on weather forewarning is significant and benefited the AAS farmers to a large extent through weather-tuned farming. AAS farmers reaped more yield when compared to non-AAS farmers owing to technical guidance on all cultivation aspects, especially selection of varieties, timely application of fertilizer/pesticides, inputs saving in terms of water, manpower, electricity, and fuel through proper irrigation scheduling (Prasad Rao and Manikandan, 2008; Kushwaha et al., 2008).

A farmer may want to use forecasts for decisions at a number of scales; in order to manage farm decisions; to plan water resource management depending on how much rain is expected in the catchment or to use the expected national food supply forecast to decide on the investment in inputs (Das et al., 2010). This illustrates that although users may operate primarily at one scale, their decision-making may depend on information from a variety of scales and so varying levels of forecast skill might be acceptable. Despite the scale of action and decision-making, it is paramount to accompany improved dissemination with improved explanations of forecast characteristics and limitations. Although seasonal forecasts are expected to be used more frequently in the future, the cost of taking precautions (based on the forecast) must be weighed against the savings that the precautions would bring if the unwanted climate event occurred. Users of seasonal forecasts could, for example, be more actively engaged in economic evaluation assessments (Richardson, 2000) to get an idea of the potential rewards and penalties accrued in unfavourable weather situations.

Much has already been reported by the senior author of this paper on the context of farmers’ needs for agrometeorological services, also recently (e.g. Stigter, 2007a; 2007b; 2007c; 2008a; 2008b; 2008c; 2008d; 2009b; 2010a; 2010b). To further characterize this context, we therefore use in this paper some recent reviews of this context in which we recognize that of our own approaches.

Subsequently we will argue that in new educational commitments, when well institutionalized (Stigter, 2009b), the understanding of farmers' needs can be extended and handled to redress the situation using agrometeorological services. The remainder of the paper illustrates this approach with a series of case studies of best examples of agrometeorological services.

Context: the existing situation

Africa

Grain yields have remained stagnant in Africa because of high temporal rainfall variability, significant spatial soil nutrient heterogeneity, and weak and volatile markets. This combination calls for location-specific interventions that are aimed at enhancing farmers' capacity to buffer water variations and address nutrient deficits. A massive investment in African agriculture is indeed required, primarily focused on the creation of knowledge that does justice to the local variation in water and nutrient availability. It should aim to empower farmers to experiment and be innovative, and remake agricultural extension and agricultural engineering (Van der Zaag, 2010).

Water uncertainty discourages poor farmers to invest in the soil, and especially in fertilizer — a bad rainy season will lead to crop loss and thus to loss of the money invested. This is a risk that poor farming households cannot simply afford to take. The solution to this phenomenon is clear: neutralize the stochastic constraint first, even though the lack of nutrients may be the largest constraint, by finding ways to enhance farmers' control over water, be it rainfall and soil moisture (green water), water in rivers and aquifers (blue water) or combinations (Van der Zaag, 2010). Even drought is relative, at least in Australia (Box IV).

Box IV. Even drought is relative, at least in Australia

The definition of drought is difficult because the dryness may be of different types, or may have different effects, and hence require different responses. Often there is reference to four types of drought:

- Meteorological drought: too little rain
- Agricultural drought: insufficient soil moisture for adequate plant growth
- Hydrological drought: insufficient runoff or deep drainage to replenish streams and groundwater
- Socio-economic drought: economic effects of drought and the effect of dryness on human well-being, including mental health.

A drought has length, severity and effect. For example:

- One day in the lower five percentile of daily rainfall has no effect on plant growth. At the other end of the time spectrum, longer periods of deviation may be more acceptable under livestock than under cropping
- If rainfall over the critical period always varies from 95-105% of optimum, the implication of a lower five-percentile is not nearly as large as if it varies from 40-160%; that is, severity of dryness is an important characteristic of droughts
- A drought must have implications to plant growth. For example, if dryness occurs during peak crop or pasture growth period, implications are more serious.

The interacting effects of all the variables listed above may be integrated with plant growth simulation models.

Over 20 years ago, when Samsul Huda moved from the Atherton Tableland in north Queensland, Australia (annual rainfall = 920 mm) to conduct climate research on the Eyre Peninsula in South Australia (annual rainfall = 325 to 450 mm), many of the local farmers were surprised that I was moving to look at cropping in such a "droughty" area (Huda, 1994). What they failed to realise was that I was moving to a different climate (Mediterranean *versus* Monsoonal) with a very different rainfall/evaporation relationship during the growing season. In similar fashion, given the various definitions of drought one cannot say that Australia will be in a permanent state of drought under climate change. The climate may in fact become drier and hotter, and challenges to agricultural and pastoral production will be significant, but producers will respond and always have responded to climate change through a range of management practices, or through a complete change in land use (Coughlan and Huda, 2008).

The definition of drought for an existing climate must therefore be related to Exceptional Circumstances *for that climate* and not for *an historical climate* before a permanent or cyclical change occurred. Despite the uncertainties associated with future climate projections it may be necessary to define exceptional circumstances based on a combination of the last few decades in the historical record and the next few decades in the future projected climate. Coping with risk for managing crops and livestock will tend to be location and environment specific (Huda et al. 2010). Many issues are more serious under livestock enterprises than under cropping. In cropping, the farmer has the option of not planting. Under livestock, the grazier must still feed or reduce stock, a major management decision. All drought management policies and strategies will have tradeoffs. Some policies will have unintended and often off-site consequences, and these must be managed.

In conclusion, the word "drought" has many connotations to many people, and for development of Drought Policy, possibly the word "drought" should be substituted with something like "Exceptional Circumstances (Dryness)".

The focus of such a farmer-centred approach would first be to enhance the capacity of farmers

(i) to observe site-specific biophysical and climatic phenomena,

(ii) to compare these with those in neighbouring fields, and, in processing this information,

(iii) to conclude which technologies and strategies can suitably drought-proof their farming system, and which organic or inorganic materials are needed and available to balance the soil nutrient status for optimal growth.

The second step would be to facilitate farmers to indeed make the required investments, for example, through low-interest credits and crop insurance schemes (Van der Zaag, 2010; for an approach in Asia, see Rothermund, 2009; see also Stigter, 2010a).

In such an approach, irrigation is not an end but a means; the end being to make farming livelihoods more resilient, and prosperous, in the face of high heterogeneity and high uncertainty. Indeed, means other than irrigation are, in particular contexts, likely to be more appropriate. Such a farmer-centred capacity development approach is currently lacking in most African agricultural extension systems, which have tended to favour simple and blanket recommendations that were based on the science of the 1960s and 1970s (Van der Zaag, 2010). The need for agrometeorological services in the livelihood of farmers in Africa must be seen in this context (see also Stigter, 2010a). But the boundary conditions for good policies must be understood (Box V).

This also has far-reaching implications for the rural educational systems and the curricula that produce agricultural extension workers and their lecturers. It will also have implications for country-specific and locality-specific research into soil fertility, soil and water conservation techniques and practices, and irrigation technologies. Moreover, it requires the development of new modes of on-farm research experimentation with, and by, farmers. In short, the envisaged approach is knowledge-intensive (Van der Zaag, 2010; see also Stigter, 2009a; 2009b; 2009c; 2010a; 2010b).

Box V. Boundary conditions from South Africa

In recent years, the agricultural sector in South Africa has undergone marked changes in policy and farmer support (Vink and Kristen, 2003). Land-reform policy, deregulation of agricultural marketing boards and the reduction in subsidies to the poor farmers have meant that several farmers have either had to find alternative agricultural activities like farming alternative crops (e.g. asparagus instead of maize); switching into cattle farming from maize farming and considering other ways to manage their agricultural risks (e.g. private companies, future trading etc.). Not all these alternate options are open to all farmers; there are many farmers who are unable to access such arrangements, and in their opinion, they face a political environment in which the government appears either to be unhelpful or to be threatening (Schirmer, 2000; Klopper et al., 2006). The use and uptake of forecasts therefore needs to be viewed within the broader perspective of what is 'do-able' given the current agricultural environment. Small-scale or smallholder farmers, as well as some commercial farmers, have repeatedly indicated their frustrations in being unable to effectively use a seasonal forecast in their farming decisions because of complex land use arrangements, lack of financial resources etc. (Archer, 2003; Ziervogel and Calder, 2003)

Asia

Traditional Farming in the Asia-Pacific region is often subsistence oriented using few or no purchased inputs. Conventional or Intensive Farming utilizes Green Revolution methods designed to maximize profit, often by extracting maximum output using external purchased inputs, especially mineral fertilizers and synthetic agro-chemicals and irrigation to support production. Organic Farming is a certifiable farm management system (with controls and traceability) that is in harmony with the local environment using land husbandry techniques such as soil conservation measures, crop rotation and the application of agronomic, biological and manual methods instead of synthetic inputs (IFAD, 2010).

Policymakers tend to be polarized in their views of organic farming; they see it either as a very lucrative modern niche or as a traditional and perhaps backward approach used by the poorest farmers. This interesting dichotomy reflects the somewhat different experiences and approaches taken in different countries. India and China are the dominant focus countries for Asia, since these two together host more than half of the world's farming households (IFAD, 2010).

In many parts of Asia, conventional farming approaches have made considerable inroads using potent fertilizers, pesticides, and herbicides along with new hybrid varietals and irrigation. For many small farmers, especially those in sub-optimal or more remote areas, such conventional methods are less relevant and traditional farming methods have changed little from the centuries-old practices of their forebears (IFAD, 2010).

Organics may be especially relevant for them. Organic agriculture has seen two primary avenues of expansion: among the smaller farmers - often poor - who either chose to eschew or could not afford Green revolution approaches; and among the commercially oriented farmers, who perceived new market opportunities in certified organic products. Consequently, projects and policies designed to support organic or eco-friendly agriculture must respond to these distinctions. Estimates for India suggest that most of its farming community relies on traditional or organic methods. China recognized the economic and ecological benefits of organic agriculture at the early stages and its local and provincial governments invested in a number of successful export-oriented enterprises (IFAD, 2010). It is in this context that needs for agrometeorological services in the livelihood of farmers in the Asia-Pacific regions must be seen (see also Stigter, 2010c).

The switch to organic farming from a traditional or rustic form of cultivation tends to increase labour costs but has positive consequences in terms of yields and profitability. For traditional producers, organic systems provide better incomes. When switching from intensive forms of agriculture to organic farming, labour costs are higher, input costs are lower, yields may be reduced and overall income is higher (due to niche markets). However, first-year losses in yields are often considerable. By the third year, yields have typically stabilized. Although some stabilize at a yield level lower than before, some of the more sophisticated farmers are able to actually improve yields using organic methods. Measuring total farm yields is more appropriate than measuring single crops, since some diversification away from dependence on a single cash crop is a characteristic of organic farming (IFAD, 2010).

Organic systems, primarily because of price premiums, are generally more profitable than conventional ones and more than make up for yields or productivity losses that may occur during transition. Greater income is the reason most farmers give for converting to organic agriculture, followed by health, ideological and environmental reasons. First movers tend to be farmers using rustic or traditional methods of cultivation and farmers with access to certification and marketing (IFAD, 2010).

Domestic market channels for organic products are limited in China, and even more scarce in India. Many farmers are primarily oriented toward export sales. However, a surprising number — while not rejecting the market — are primarily focused on the intrinsic local benefits of organic production. In such cases, lower production costs, improved soils, fewer toxic chemicals, self-reliance in inputs and harmony with nature were cited as the most important reasons for converting to organic farming. In the areas concerned, there is generally adequate availability of organic inputs and most organic projects did not suffer from negative plant health or soil fertility issues. Instead, many noted improved soil characteristics (IFAD, 2010).

Organic systems work particularly well with livestock components, especially in less fertile areas. Livestock can facilitate fertilization, provide power and fuel. They are also an excellent source of food security and income diversification. Given that labour requirements are generally higher than in conventional systems, organic agriculture can prove particularly effective in bringing redistribution of resources in areas where the labour force is underemployed. This can help contribute to rural stability, especially where labour is abundant and migration occurs (IFAD, 2010).

Organic agriculture, as a systemic development package, fits into the approach of ‘new growth economics’, that stresses knowledge and innovation as factors in production combined with new institutional models. (……) Organic farming systems embody many elements of sustainability that make them suitable tools to reduce poverty (IFAD, 2010). For rural communities it can provide improved incomes, better resource management and more labour opportunities. For agricultural competitiveness, it meets the increasing demands for improved food safety methods and traceability that are becoming the hallmark of high-value agricultural trade. For governments, organics reduce the possibility of environmental contamination, reduce the use of chemical inputs (often imported) and minimize the public health costs of pesticide poisoning. For nearly everyone involved in its production, processing and trade, organic agriculture simply earns more money (IFAD, 2010). Some more details from practice are in Box VI.

Box VI. Nutrient management and low-till experience from India and elsewhere

Since globalisation may eventually result in steep rise in fertilizer prices in the near future, bringing them beyond the reach of poor farmers, integrated nutrient management may be the key to maintain the productivity of the soils on a sustainable basis. Large numbers of experiments at research stations and on farmers' fields in India have demonstrated the importance of organics, Farm Yard Manure (FYM), compost and biofertilizers in supplementing the nutrient requirements of crops and providing stability to yields in rainfed semi-arid areas (The India-National Action Programme, 2001; Akbari et al., 2009). Fifty percent of the fertilizer N could be replaced with the use of FYM/compost in a variety of soils. Use of organic manures not only reduces the use of chemical fertilizer N requirement substantially in addition to supplementing important primary and secondary nutrients. The use of compost and FYM also improves the soils' physical condition and crop yields on a long term basis. It also improves moisture holding capacity of soils.

If availability of FYM in quantities adequate to obtain good response in field crops is a major limitation for wide adoption of this technology, alternate sources like green leaf measures and crop residues have been evaluated at a number of locations in India. In lower rainfall areas (350-700 mm) where there are little opportunities for producing green manures without competing with the main crop, strategies for non competitive production of green leaf manure and their incorporation in the soil need to be evolved . Some such approaches tried under research projects at different locations of India include bund farming where nitrogen fixing trees and bushes can be raised on either side of the field boundary bunds and the loppings incorporated in the soil. Yet another approach could be to raise a post-rainy season cover crop like horse gram /cowpea utilising the off season rainfall and ploughing it back into the soil before flowering (Katyal et al., 1994). A third approach is to raise leguminous trees or shrubs on marginal lands and incorporate the loppings in the nearby crop fields. These could be good examples of self-sustaining nutrient management systems to reduce the fertilizer cost for the resource-poor farmers.

In some developing countries, the farmers have also started to embrace approaches that keep soil structure intact and cut the high level of inputs – energy, fertilizer, pesticides and herbicides that characterize intensive agriculture. These approaches diverge significantly from the purist organic vision. In particular, they rely heavily on 'low tillage' methods which help to improve the soil, but depend partly on the use of herbicides, fertilizers and pesticides. Mainstream agronomists now acknowledge, for example, that intensive farming reduces biodiversity, encourages irreversible soil erosion and generates run off that is awash with harmful chemicals including nitrates from fertilizers that devastate aquatic ecosystems (Macilwain, 2004; Layton, 2009).

For this kind of organic movement, caring for the soil involves interspersing each harvest with a cover crop such as clover or rye that can fix nitrogen from the atmosphere. Cover crops keep down weeds, retain moisture and prevent erosion. Ploughing them into the soil at the end of the season restores the soil's organic content without the need to use synthetic fertilizer. The 'low-till' approach borrows heavily from these principles. This approach ensures that their soil is not left too open to erosion by growing nitrogen fixers between rows of their cash crops and between seasons. But low-till farmers do not completely unhitch their wagon from conventional inputs. They still use nitrate fertilizers and pesticides as needed. Before each planting, they kill the previous crop with a broad-spectrum herbicide. This lets them punch the new seed directly into the ground through the decaying plants without tilling (Macilwain, 2004).

Low-till agriculture is taking root in both rich and poor countries. Brazil has been in the vanguard of the change in Latin America. Although many of the farms that are converting to low-till agriculture are large-scale operations, the approach is also rapidly gaining acceptance on small holdings in countries like India and Ghana. On the Indian sub-continent, the area where low-till is being implemented has grown from nothing in 1977, through 100,000 hectares in 2001 to one million hectares by 2004. Besides conserving soil structure, low-tillage also reduces energy inputs. Farms in India that grow rice in the summer and wheat in the winter have cut their number of annual tilling operations from eight to one. Low-till farming also substantially reduces the need for chemical fertilizers. Cover crops provide some nitrogen initially, and then, as organic matter builds up in the soil, nitrates and other nutrients are less readily leached out of it, further decreasing the requirement for added fertilizer to offer some relief to poor farmers.

Poorer small scale farmers seem to experience a positive transition and outcomes when converting to organic farming. For many of these farmers practicing rustic or traditional methods of agriculture, transition to organic results in an increase in both yields and overall incomes (IFAD, 2010). It is, however, unknown whether it is more or less stable in the context of the presently more frequently occurring agrometeorological risks and uncertainties in Asia (e.g. Rathore and Stigter, 2007). This has to be determined by the establishment of agrometeorological services addressing the needs of these farmers the way they see them (Stigter, 2010a).

Latin America

On a regional scale, São Paulo State in Brazil started a weather based Agrometeorology Warning System at the Agrometeorology Information Center

(CIIAGRO) in 1988, which gives support to agricultural production and crop development. It is an operational framework that provides agrometeorological information to farmers, extension services and other stakeholders regarding the type of soil, crop development, agricultural practices, pest management, irrigation requirements, climatic risks (frost, drought, dry spell), stored water in the soil, water balance, crop yields, and weather forecasts. Timely and accurate agrometeorological information and forecasts have proven to be effective tools for critical decision making in routine farm operation, and medium and long-term planning (Singh et al., 2008; see also Brunini et al., 2010).

The ability to disseminate timely and relevant agrometeorological information to the user community, so that it can act on it, is of paramount importance for any Agrometeorology Service. Information and Communications Technologies (ICTs), including the internet, have become rapid and dynamic means for the dissemination of agrometeorological information in many countries. In rural settings where internet facilities are unavailable, the traditional means of information dissemination such as radio, television, and the news media can be used in combination with limited ICTs to get the message across to a much larger audience (Singh et al., 2008; see also Stigter et al., 2007; 2010b and Brunini et al., 2010).

Also in Latin America, weather based agricultural information is part of a continuum that begins with scientific knowledge and understanding and ends with the evaluation of the information. Intermediate processes are the collection of data, changing data into useful information and dissemination of information. While scientific knowledge and understanding transcend national borders, the remaining components of the continuum may differ between developed and developing countries. The reasons for these differences are mainly a function of human, financial, and natural resources. In order for this information to be useful, it must be accurate, timely, and cost-effective, i.e. the benefit to be gained from implementing the information is more than the cost to obtain the information (Singh et al., 2008; see also Brunini et al., 2010).

Critical questions have been raised but clear responses are linked mainly to the scientific, technological, and social developments that will take place in the 21st century. There is no doubt that information and communication technologies will improve in the future, as will accessibility. What will limit the generation and dissemination of agrometeorological information in the future is the same as it is today: the interaction of people, from scientist to extension worker to farmer, in the continuum from basic understanding to practical applications (Singh et al., 2008).

Thus, to prepare for the future now, we have to better integrate the human capital available at all levels of organization. It is time to integrate and make it a habit to utilize all the vast information available online in preparing weather based agro-advisories for in-season agricultural operations (Singh et al., 2008; see also Stigter, 2010). See for an example from South Africa Box VII. Agrometeorological services have to be established together with farmers, addressing their needs, to get this done (Stigter, 2010).

Box VII. Early warning of Downy Mildew in vineyards in South Africa, among others communicated on the internet.

One of the most important vineyard diseases in the Western Cape is Downy Mildew (*Plasmopara Viticola*) as it can develop and spread very quickly and so cause large crop losses in certain years, depending on the weather conditions. Researchers of the Agricultural Research Council (ARC) worked together with growers in an attempt to characterize the weather conditions conducive to the outbreak of the disease. They monitored the weather conditions over a number of years on the farms together with the outbreaks of the downy mildew in the vineyards. The growers must make decisions on whether or not to spray; the frequency of the applications and which agrochemicals to use. They have to balance the number of applications according to the economics while minimizing pollution effects, yet need to prevent crop failure due to infection. A computer model called Donsige Skimmel Vroeg-Waarskuwingsmodel (DSVW) (Afrikaans for "Downy Mildew Early Warning Model") (Haasbroek, 2006) provides a user friendly graphical output of the past weather variables (up to 3 weeks), and an indication in three different colors of a high, medium and low chance of possible favorable periods for both primary and secondary infection occurrence. The input needed is the hourly weather data downloaded via telephone modem from the automatic weather stations each day. This is then used to run the model and generate the output which is either emailed or faxed to the growers for a nominal annual fee (Walker and Haasbroek, 2007).

Some of the users have a weather station on their own farm (about a third), while others use data from a neighboring farm or an ARC weather station. Many producers (70%) have been receiving these outputs for 5-10 years and use the information about the favorable weather conditions for downy mildew infections given by DSVW to better manage their preventive spray programmes so as to minimize crop damage. About half of them normally work on a regular repetitive spray programme spaying each part of the vineyard every two weeks. The model output helps more than a third of them to take a decision about which chemicals to use and whether to spray with systemic or contact chemicals. Others use the output to decide on an additional spray if the model indicates that weather conditions have been highly favorable for infection with downy mildew. Producers have asked for a prediction of infection in a forecast period, so this is being developed. The operation of this agrometeorological service for grape growers was supported by the ARC in providing and maintaining the infrastructure of the weather station network and the computer connections. The national department of Agriculture, Forestry and Fisheries provided policy support by allowing the information to be delivered via their web pages. This shows that the service to the farming community must be a joint effort across organizations, government departments and grower groups, each playing a supporting role.

Agrometeorological information for farmers via a web site can be limitless, especially if the package is prepared in a collaborative effort with the agricultural experts and farm extension service personnel/agro advisory services, which is the recommended approach (see for example the website http://hau.ernet.in/coa/agromet.htm). However, it will serve no purpose if the information is complex and irrelevant to the specific needs of the users. Consequently it is important that the designers of the web site bear in mind how to structure the content of the web pages in order to prioritize the users needs and present the information in a user-friendly manner that is easily accessible. A recommendation that is always made by extension officers and farmers is that the agrometeorological information must complement the phase of the cropping season and the cycle of livestock rearing. In other words, the agrometeorological information should be crop/livestock relevant and must be integrated within any agronomic advisory or bulletins emanating from the extension services/farm advisory services (Singh et al., 2010).

Recent efforts in capacity building for operational agrometeorology in Brazil have a very profound impact on sustainable agricultural development under ensuing scenarios of climatic change and variability. Various institutions and scientists across the country, supported by federal and state government as well, are maintaining networks of weather stations and generating agrometeorological products for the benefits of end users, policy makers and other stake holders (Singh et al., 2008; see also Brunini et al., 2010). The establishment of agrometeorological services, also related to the needs of poorer farmers, is the final step to be made in this process in Latin America and elsewhere (Stigter, 2010a).

Context: the future

We now propose that for the future, the major connections of the three principal regional issues treated in the context of the existing situation: water (illustrated for Africa), fertility (illustrated for Asia), extension (illustrated for Latin America), have to be made by two major connecting principles: agroforestry (and other multi-functional agriculture) and communication. The first connects water and fertility issues (in monocropping and multiple cropping without trees (e.g. Walker et al., 2011)), the latter connects extension issues.

A connecting principle: Agroforestry (and other multi-functional agriculture)

The increasing loss of forest and other tree resources in tropical countries leaves farmers without their food and other products that used to be gathered locally. This, coupled with land degradation, creates a poverty trap from which it is difficult for smallholder farmers to escape. To address these problems, the domestication of new perennial crops from traditionally important indigenous trees is seen as a way to diversify farming systems making them more sustainable through the provision of a range of products and environmental services. This enriches existing mixed tree/crop farming systems and creates new ones that are more productive and enhance the livelihoods of poor households. A participatory approach to tree domestication is used to ensure that farmers' needs are met (Leakey et al., 2010). This approach is in accord with the findings of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). The latter recently identified the need for agriculture to be more multi-functional and to simultaneously achieve economic, social and environmentally sustainability by restoring

(i) biological resources and natural capital (soil fertility, water, forests, etc),

(ii) livelihoods (nutrition, health, culture, equity, income), and

(iii) agroecological processes (nutrient and water cycles, pest and disease control, etc.) (Leakey et al., 2010; see also De Melo-Abreu et al., 2010).

Land degradation is one of the most serious problems facing agriculture as it affects 2000 million hectares (38% of world's cropland) and is intimately interconnected with increasing population densities, declining livelihoods, malnutrition, hunger and poverty. To rehabilitate degraded land and restore sustainability requires

(i) soil fertility replenishment,

(ii) diversification at the plot and landscape level and

(iii) perennial vegetation to provide environmental services and increase the number of niches in the agroecosystem.

The 'Green Revolution' promoted intensive production of high-yielding staple food crops on land cleared of much of its natural vegetation. However, in many tropical countries poor farmers are unable to have access to agricultural inputs such as fertilizers and pesticides. Consequently, other ways have to be found to maintain and restore soil fertility and maintain sustainable production. Examples are: low-input resource-conserving technologies based on integrated management systems and an understanding of agroecology and soil science (e.g. agroforestry, conservation agriculture, ecoagriculture, organic agriculture and permaculture), which minimise the need for high inputs. These low-input systems are pro-poor approaches to agriculture, that can also build social capital at community and landscape levels, and are especially relevant to smallholder agriculture in the tropics – i.e. multi-functional agriculture (Leakey et al., 2010; see also Stigter, 2010a).

With the exception of agroforestry, there has been very little plant breeding or crop domestication aimed specifically at these forms of low-input agriculture, yet domestication has an important role to play by promoting the diversification of farming systems with new crops. The domestication of agroforestry trees was initiated in the mid 1990s, by the World Agroforestry Centre (ICRAF) and its partners, aimed at improving the quality and yield of products from traditionally important species that used to be gathered from forests and woodlands (including savannas and agroforestry parklands, e.g. Stigter, 2010a). As well as meeting the everyday needs of local people, these products are widely traded in local and regional markets and so have the potential to become new cash crops for income generation and to counter malnutrition and disease by diversifying dietary uptake of micro-nutrients that boost the immune system. These indigenous tree species also play an important role in enhancing agroecological functions and, through carbon sequestration, help to counter climate change (Leakey et al., 2010; see also De Melo-Abreu et al., 2010).

Agroforestry seems to be particularly relevant to establishing a multi-functional agriculture. See also experience from India in Box VIII. Like the other systems, it addresses the issues of soil fertility management; the rehabilitation of degraded farming systems; loss of biodiversity above and below ground; carbon sequestration; and soil and watershed protection. However, in addition, agroforestry also provides three crucial outputs that are not provided by the other systems, namely:

(i) useful and marketable indigenous tree products for income generation, fuel, food and nutritional security/health and the enhancement of local livelihoods ;

(ii) complex mature and functioning agroecosystems akin to natural woodlands and forests;

(iii) linkages with culture through the food and other products of traditional importance to local people (Leakey et al., 2010).

(……)

On the 'down-side', trees are competitive with crops and the net benefits of agroforestry can be slow to materialize due to the longevity of trees. However, techniques such as the vegetative propagation of ontogenetically mature tissues speeds-up the benefit flows by creating cultivars from parts of the tree which already have the capacity to flower and fruit without going through a long juvenile phase (Leakey et al., 2010; see also De Melo-Abreu et al., 2010, Stigter, 2010a and Walker et al., 2011).

Box VIII. Agroforestry and some other multi-functional agriculture experience from India

In India, agroforestry and some other multi-functional approaches that include systems like agrosilviculture, agrihorticulture, hortipasture and silvipasture, have been evaluated as alternative or alternate land use systems in order to provide stability to farm income and also utilize marginal lands for production of fodder, fuelwood and fibre (Pathak, et al., 2006). This helped improve the livelihood of small-scale farmers. Management of lands of lower quality through such interventions is the best way of integrating livestock production in semi-arid areas, thus contributing to the sustainability of the production system. This approach not only provides fodder, fuelwood, timber and fruits but also enhances the quality of the resource base through greater biomass production and providing a land cover for most of the year, which constitutes the basic step for control of soil erosion by wind and water. Off-season rainfall which otherwise goes unutilized in single kharif cropping areas can thus be best utilized with such production systems. Trees also make the microclimate more favourable to crop growth (see many case studies in Stigter (2010a) and at the end of this paper).

Multilocational studies under the All India Coordinated Research Projects and under agroforestry networks have led to the identification of several agroforestry systems for different locations of the rainfed regions in India (Pathak et al., 2006). In alley cropping, the perennial component is grown as hedge rows largely on contour lines, and the annual crop in these alleys. The prunings from the tree component can be used as fodder during drought years or applied in the cropped field as mulch cum manure. Although, the tree component competes with the annual crop for moisture and nutrients, leading to decreased crop yields in drought years, the fodder from the tree supports the livestock. Moreover, by cutting the hedge rows, competition with the crop can be minimised. In areas where supplemental irrigation is possible, agrihorticulture provides significantly greater income than arable cropping. A number of fruit trees and crop combinations have been identified and the water management techniques standardised. Silvipasture was proven to be an ideal land use system for marginal/degraded lands where a perennial tree component like *Leucaena leucocephala* is planned either with *Cenchrus cilliaris* or *Stylosanthes hamata*. Ley farming is another approach where a legume or non-legume forage is rotated with cereals. This system improves soil quality besides providing fodder. The adoption of agroforestry and other multi-functional practices thus will inevitably bring far-reaching positive consequences in the livelihood of the poor farmers; they will not only improve their own lives, but also help in changing society at large.

A connecting principle: Communication

Gommes et al. (2010) explain the best approach to agrometeorological services as FADO (Farm Adaptive Dynamic Optimisation). That is a technologically sophisticated approach that basically constitutes a modernization of response farming. It is based on long-term original experience in Mali (e.g. Stigter, 2010a; 2010b).

Our starting point is the following figure from Gommes et al. (2010):

Based on African, Chinese, Indian and Indonesian (Stigter, 2010a) experience, FADO may now be considered a technically feasible approach, which, however, is rarely implemented in developing countries. The three “joint actors”, from left to right in the figure: (1) the farmers in the villages, (2) the Extension Services and (3) the supporting scientists, including the providers of client friendly weather and climate information, all need to be exposed to “Capacity Building” initiatives.

The last group of actors are what we called “product intermediaries” (AEIBs, in Stigter, 2009c; 2010a, see List II) and they ideally are in extension wings of the product providers: NMHSs, universities and research institutes. The Extension Services group of actors is what we called “extension intermediaries” (AEIAs, in Stigter, 2009c; 2010a, see List II). For these two groups of “joint actors” we presented curricula in Stigter (2009c; 2010a, see Table 1) and they should be the facilitators in such educational commitments in rural areas as Farmer Field Schools and Climate Field Schools for the first group of “joint actors”, the farmers. Again with the latter’s differentiation applied (Stigter et al., 2007). And the trainers of these trainers must be found in the above mentioned institutions delivering the products, as far as information at the right hand side of Figure 1 is concerned, as well as in the extension institutions.

List II. Training of extension intermediaries (after Stigter, 2009c).

1. An agricultural meteorology-related syllabus for the in-service training of AEIAs (Agrometeorological Extension Intermediaries functioning in the A-Domain (Stigter, 2010a))

Elementary

The elementary components of this syllabus comprise the following:

(a) Review of local context concerning administrational issues: functions and responsibilities;
(b) Review of local climate issues, including traditional knowledge;
(c) Review of farming systems in the subregion/country/region/continent concerned;
(d) Production constraints within the farming systems reviewed;
(e) Fields of agricultural meteorology relevant to local agriculture;
(f) Agrometeorological components of identified production constraints;
(g) Assessment of needs identified by the farmers in the various systems.

Practicals with farmers are possible on the last two subjects, and additional ones with AEIBs (Agrometeorological Extension Intermediaries functioning in the B-domain) (Stigter, 2010a) as indicated below. The results of such practicals should be discussed with AEIBs in joint classes.

Advanced

The advanced components of this syllabus comprise the following:

(a) Review of processes of change (economic, social, environmental, and so on) taking place in the subregion/country/region/continent concerned;
(b) Extension approaches suitable in the farming systems reviewed for the production constraints identified;
(c) Policies of existing extension and their decentralization;
(d) Extension agricultural meteorology locally available to meet assessed needs;
(e) Agrometeorological services already applied or tried;
(f) New extension agricultural meteorology possible;
(g) Constraints in applying extension agricultural meteorology through agrometeorological services and their relief solutions.

Practicals with farmers are possible on the last three subjects and additional ones with agrometeorological extension intermediaries as indicated below. The results of such practicals should be discussed with AEIBs in joint classes.

2. An agricultural meteorology-related syllabus for the in-service training of AEI Bs (Agrometeorological Extension Intermediaries functioning in the B-domain (Stigter, 2010a))

Elementary

The elementary components of this syllabus comprise the following:

(a) Needs assessments concerning the agrometeorological products required by farmers and farming systems;
(b) Products available from weather services, research institutes and universities directed at farming systems in the subregion/country/region/continent concerned;
(c) User friendliness of those products, as assessed by clients;
(d) Documented or remembered use of such products and their successes and failures and assessment of their causes.

Practicals are possible together with the AEIAs on the last two subjects. The results should be discussed in joint classes.

Advanced

The advanced components of this syllabus comprise the following:

(a) Needs for additional products from weather services, research institutes and universities;
(b) How to commission these organizations to provide such products;
(c) How to make such products as user friendly as possible for the farming systems concerned;
(d) Discussions on potential new products with prospective users;
(e) Bringing new products into new or existing agrometeorological services.

Practicals are possible together with the AEIAs on the last two subjects. The results should be discussed in joint classes.

FADO finds its justification, among others, in the fact that subsistence agriculture is expanding more and more into marginal areas, with at least some intensification taking place. Smallholders face the problem of further degrading their environment, increasing variability of their production, while at the same time having to produce more in a context of growing populations and increasing urbanisation (Gommes et al., 2010).

FADO aims to develop agrometeorological services to help farmers stabilise their production and income by making better use of environmental resources, such as climate (rainfall, sunshine), soil etc. The advice is based on local farming, historical weather data (of coping with risks) together with actual current season weather conditions. FADO includes the following steps/components:

(1) collect real-time local, village-level weather, soil and crop (e.g. phenology) information and transmit it to a central location, for instance to the national or regional Agrometeorological Service, where the socio-economic data have been

made available;

(2) simulate management options based on local conditions (e.g. soil, farming practices) and market data (crop and input prices);

(3) feed back the advice/management options to the farmers in the village. These services are based on local farming systems (crops, soil, practices), local historical weather data (for risk assessment) and actual local current season weather conditions, taking into account seasonal weather forecasts and historical local climate risk (Gommes et al., 2010).

Gommes et al. (2010) indicate that in the process of Figure 1, Agricultural Extension Services are being reoriented in order to

- respond to the need for participation by a wide range of stakeholders,

- improve responsiveness and accountability, and

- include non-conventional messages that incorporate environmental issues.

Main orientations of these Extension Services have then become (Gommes et al., 2010):

(i) decentralised and open to multiple delivery mechanisms, including delivery by private-sector enterprises, NGOs and producer associations and

(ii) responding to tremendous differences in needs and priorities among farmers according to their level of access to resources, social and gender status (e.g. for China in Stigter et al., 2007; see also Chambers, 1990).

Within this key approach to establishing a farmer-centred decision making process at the community level, an educational approach appears essential to stimulate adapted use of improved technologies in developing countries (see also Stigter, 2009b; 2010a). Targeted capacity building initiatives are an essential component of the communication process (Gommes et al., 2010).

Farmer/Climate Field Schools for decision making on coping with diseases and pests are an example (Stigter and Rathore, 2009; Stigter, 2010c). Climate Field Schools have recently been discussed by Winarto et al. (2008) and Stigter (2009d; 2009e). These are the ultimate new educational commitments of governments with which new agrometeorological services are established, with the connecting principles of agroforestry and communication in action. While in these participative approaches the understanding of farmers' needs can be extended and used to redress and improve the existing situations earlier described in this paper, using these agrometeorological services.

Case studies

A series of case studies will now be used at the end of this paper to further illustrate agrometeorological services earlier developed and now in use. These case studies come from across a wide range of farming systems and many show a farmer-innovative design improved by the use of science. Such actual services must then be supported by a policy environment that assists their further establishment and dissemination.

More details on most of these case studies shortly reviewed below can be found in Part II of Stigter (2010a), where 30 of such examples are dealt with through protocol forms filled with similar kinds of information throughout these forms. This applies also to papers published on these cases. The first six examples from Sudan (3), Cuba, China and Kenya were selected because of the prizes they obtained in the INSAM contests of best examples of agrometeorological services of 2006 and 2007. The 4 additional Chinese examples were selected because they belong to the earlier results of the search work of Zheng Dawei and Kees Stigter in China, with the strong collaboration of the mentioned lead authors, be it sometimes in an updated version (Stigter et al., 2008a; 2008b; Stigter, 2010a).

At the end of each description, we use the word “policy” (in “policy support”) in the meaning of “a set of interrelated decisions taken by an actor or a group of actors concerning the selection of goals and the means of achieving them within a specified situation, where those decisions should, in principle, be within the power of those actors to achieve” (Amupanda, 2010). Applying the scheme of Figure 1 to these cases shows that reality is sometimes a lot simpler because of the very specific character of the problems to be tackled. But the principles remain, be it that in almost all cases a lot more information would be required to improve on the solutions provided. This is where the knowledge intensity (see the last sentence of the sub-section on Africa in the section “Context: the existing situation” above) of these agrometeorological services can still be improved by applied agrometeorologists. That actually should be our main task for the future.

I. Shelterbelt design for protection of irrigation canals and agricultural land from blown sand encroachment (Ahmed E. Mohammed, Sudan)

The first prize in the 2006 INSAM contest on "Best Examples of Agrometeorological Services" was given by the INSAM jury to Prof. Ahmed Eltayeb Mohammed and Prof. Hussein Adam from Sudan for their example of understanding the mechanisms of a Eucalyptus shelterbelt to prevent sand invasion in the Gezira Irrigation Scheme, Sudan.

A *Eucalyptus microtheca* shelterbelt, as an agroforestry technique which uses trees to protect land from moving sand encroachment, was planted by the Gezira Board and Forestry Authorities in an attempt to prevent such an invasion of sand. To understand the mechanism by which sand was settled within and in front of the shelterbelt, on their request a quantitative study was undertaken, that also needed to come up with design rules for shelterbelts to most efficiently combat such sand invasions. Such design rules must be considered to be an agrometeorological service to these authorities and to the farmers whose land got protected.

It was proposed that dense shrubs in the front row(s), followed by tall strong trees, would do best from the windward wind reduction point of view. Some physical land treatments were suggested at the windward side of the belt, to trap some of the encroaching sand and hence increasing the life span of the belt. Some of these design recommendations, that were offered as an agrometeorological service, were subsequently used in substantial belt extensions by the Authorities. These extensions for the time being successfully protect endangered parts of the Gezira scheme. The initial policy support for this capacity building of protection of agricultural land from sand encroachment came from various government institutes and institutions, including a local University that was supported by a Dutch University.

II. Design of improved underground storage pits (matmuras) for sorghum in cracking clays (Ahmed T. Abdalla, Sudan)

The second prize in the 2006 INSAM contest on "Best Examples of Agrometeorological Services" was given to Dr. Ahmed el-Tayeb Abdalla and Dr. Nageeb Ibrahim Bakheit from Sudan for their example of showing possibilities for increased lengths of times of traditional underground storage of sorghum (dura) grain in small cylindrical pits in central Sudan.

Traditionally, the so called *matmuras* are dug in black cotton soil where preferably there are no cracks or sand or chalk deposits. Cylindrical in shape, they can hold from 2 tons to more than 150 tons of sorghum grain, but they are always dug in the same way. Subsistence farmers generally use sizes for 2 to 5 tons, farmers that also supply local markets use sizes for 5 to 10 tons, traders use sizes for 10 to 50 tons, although occasionally larger sizes do also occur.

Microclimate measurements of grain moisture content, grain temperature and pit air carbon dioxide content, in experimental pits, made it possible, as an agrometeorological service, to test and improve their designs. In farmer derived innovations of using shallower pits (50 cm in the experiments), applying chaff linings at bottom and sides of these shallow pits (of at least 25 cm before compression by the grain filling in these experiments), made safe storage possible during at least two consecutive rainy seasons. Wide above surface caps (1 m beyond the pit diameter all around in the experiments), to diminish chances of surface cracks leading water to the grain, were a necessary condition added by the research experience. The policy support for this capacity building to extend sorghum grain storage in underground pits came, at the request of a State Government, from a local University that was supported by a Dutch University.

III. Design of sand settlement of wind blown sand using local trees and grasses (Nawal K.N. Al-Amin, Sudan)

The first prize in the 2007 INSAM contest on "Best Examples of Agrometeorological Services" was given by the INSAM jury to Mrs. Dr. Nawal K. Nasr Al-Amin (Sudan) and Prof. Ahmed El-Tayeb Mohammed (Sudan) for their example of “Guiding wind, sand and people in revegetation of desertified areas to fight sand encroachment”.

Several decades ago, after the African droughts of the mid-sixties, the first sand dunes appeared in the area south west of the Gezira Irrigation Scheme, although so far the longitudinal dunes on the west bank of the White Nile appeared to be the sand dune frontier. Rehabilitation of the sand invaded areas using desert vegetation, that efficiently reduces wind speed close to the ground, this way settling sand, appears the best solution in a second front against desert encroachment. In consultation with reforestation authorities, a quantitative study of sand and dune movement in the past and at present was undertaken. This research also needed to come up with design rules for revegetation.

Quantitative agrometeorology of simple container trickle irrigation, and of wind flow and sand deposition guidance around single trees and bushes, and composite grasses, led to selection of suitable species for use in combating sand encroachment in the area. As an agrometeorological service, four species investigated appeared worth considering under the conditions of the source areas for sand settlement under windy conditions. The policy support for this capacity building to design suppression of sand encroachment by revegetation came from various government institutes and institutions, including a local University that was supported by a Dutch University.

IV. Agrometeorological service for irrigation advice (Ismabel M.D. Hurtado, Cuba)

The second prize in the 2007 INSAM contest on "Best Examples of Agrometeorological Services" was given by the INSAM jury to Mrs. Ismabel Maria Dominguez Hurtado (Cuba) for her example of “Agrometeorological service for irrigation advice in Villa Clara, Cuba”.

This service is based on the demands and experiences of farmer communities together with irrigation specialists of the agricultural entities of Villa Clara. The agrometeorological advisory service for irrigation in Villa Clara helps producers to achieve proper use of water resources and aims to allow users to manage water efficiently, giving the crop enough water in a timely manner.

The information of water consumption of plants is given to the producers with a frequency of every ten days. The service is transmitted through local radio broadcasting, with specific timetables. Evapotranspiration of the previous ten-day period is evaluated, and this variable is forecasted for the current decades according to the weather forecast for the next ten days and climate forecasting. Calculation of evapotranspiration is done by the Penman/Monteith formula recommended by FAO (e.g. Allen et al., 1998), with the values of resistance and default coefficients resulting from the calculations for the standardized conditions in Cuba.

The policy support in this capacity building for the development of participatory irrigation advice as an agrometeorological service came from a Provincial Government Meteorological Service.

V. Frost forecast service in Inner Mongolia (Wei Yurong, China)

The third prize in the 2007 INSAM contest on "Best Examples of Agrometeorological Services" was given to Mrs. Wei Yurong (China) for her example of “Frost Forecast Service of Inner Mongolia in 2007”.

The duration of the frost free period in Inner Mongolia Autonomous Region is from 70 to 181 days. It is shorter in the Northeast and longer in the Southwest. In 2007, in order to make it possible to organize protection from the frost, the Meteorological Bureau of Inner Mongolia (Provincial Meteorological

Administration) published a detailed frost forecast for the whole autonomous region. It listed the average first frost appearance time, and gave the forecast date for 2007.

At the same time, the publication pointed out the damage from frost and gave suggestions of defense interventions. The defense suggestions included adopting irrigation, making fire to produce smoke in the cropland, and sprinkler irrigation against frost for protection, this way mitigating the damage from the frost. The policy support in this capacity building in frost forecasting as an agrometeorological service came from a Provincial Government Meteorological Service, with the approval of the China Meteorological Administration, Beijing.

VI. Design of protection of sloping land from soil loss and water run-off using hedgerow intercropping (Josiah M. Kinama, Kenya)

The first honorary mention in the 2007 INSAM contest on "Best Examples of Agrometeorological Services" was given to Dr. Josiah M. Kinama (Kenya) and Prof. C.K. Ong (Malaysia, working in Kenya) for the example of "Design of protection of sloping land from soil loss and water run off using hedgerow intercropping".

Land scarcity forces farmers in the semi-arid areas of Kenya to cultivate more sloping land. Contour hedgerows should be able to capture runoff water and soil which would otherwise be lost from hillside cultivation, and thereby compensate at least in the long run for the extra resources required for tree growth. *Senna siamea* contour hedgerows with interrow distances of 4m were compared "on-station" for erosion control on a 14% slope of an Alfisol soil, intercropped in rotation with maize and cowpea, without the use of fertilizers. Alternative grass strips were on average more than one meter wide and their centers on average around 6.5 meters apart. Hedgerows were cut to a height of 25 cm two weeks before the onset of the rains, and the prunings spread uniformly over the soil surface. The grass strips were cut twice in the season, two weeks before planting the crop and at harvest, also reducing competition with associated crops.

Cumulative results for four consecutive seasons showed that the most successful treatment for soil loss and run off reduction was the combination of hedgerows and surface spreading of their prunings as mulch, just before the start of the two annual rainy seasons. This reduced cumulative runoff from close to 100 mm to only 20 mm and reduced cumulative soil loss from more than 100 ton/ha to only 2 ton/ha. This was at the expense of 35% of the maize yields but only 25% of the cowpea yields, because mean rainfall was above average during the two cowpea seasons. These rather high yield depressions were due to higher competition because of aging of the hedges, that had also been used in earlier experiments, along with fertilizers.

The grass strip results for runoff and soil loss reduction were halfway between the values for the hedges with and without mulch application, but yield reductions were the highest of all treatments. For lower input farmers, grass strips and highly competitive trees with high biomass density close to the ground, even when less efficient in direct erosion control, may deliver highly needed thatching material and/or fodder and save money for durable erosion control embankment stabilization. The policy support for this capacity building in design of water run-off and soil loss reduction plantings came from various government institutes, including a local University that was supported by a Dutch University, and ICRAF (now Wold Agroforestry Centre).

VII. Improving microclimate for water melon by covering sandy soils with pebbles (Liu Jing, China)

In these (semi-)arid areas with largely late summer and autumn rains, this farming practice enhances water infiltration and reduces the evaporation of soil moisture and water run-off. Stigter (2006) and Stigter in WMO (2010) have preliminarily described and discussed the example of water melons grown in an improved microclimate created by covering sandy soil with eight to ten cm of pebbles collected from river beds, explaining the wind erosion protection, the soil surface evaporation prevention and the warming of the seed bed so created.

It should firstly become clear that most of the few rains fall in autumn (as we experienced ourselves abundantly these days). The pebbles protect against evaporation of this water for use in early spring sowing. Without the pebbles, the soil could be dry till half a meter depth in spring! It appears that the seeds are brought into holes in the layer of pebbles that remain a cavity, over which plastic is brought by some farmers.

It has been measured that at the bottom of such covered cavities the soil surface temperatures can be in the order of five degrees higher than at the pebble surface, particularly at night. Because of the importance of early sowing due to the length of the growing season, this can be an essential frost protection issue of the method. The plastic can protect the seeds and seedlings against frost in the early days, but it is not applied by all farmers, determined also by the location. Further details are also in Stigter et al. (2008a). The policy support in this capacity building in microclimate improvement came form a Provincial Government Meteorological Service, with the approval of the China Meteorological Administration, Beijing.

VIII. Winter straw mulching increasing water use efficiency and yields in winter wheat (Li Chunqiang, China)

Straw mulching forms a layer that interrupts the water and heat exchanges between the atmosphere and the original soil surface. So there is a warming effect in wheat fields mulched with straw in winter. Compared to bare soil, the turbulent exchange coefficient is increased, so is the mulch surface temperature, so the sensible heat flux. However, latent heat flux, that is evaporation, is decreased by the barrier to a large extent. Soil heat flux is significantly reduced due to the insulation properties of the mulch. In other words, with straw mulching, the variation of soil temperature becomes relatively stable, which prevents the winter wheat from freezing. In spring, straw mulching tends to lower the soil temperature, slowing down the rising pace of temperature. This tends to prolong the spiking stage of winter wheat and to produce larger ears on condition that supply of both water and fertilizer are sufficient.

Straw was found to be the best mulching material and the appropriate amount is 4,500-6,000 kg ha^{-1}. Before mulching, straw should be chopped up to prevent it from pressing the seedlings. The most effective mulching period for winter wheat is from the beginning of winter, which is normally in the second or last decade of December for wheat growing areas in central and southern Hebei Province. Any earlier mulching may lead to weak seedlings, while delayed mulching may shorten the effective period and its benefits will be compromised.

Straw mulching has different effects on soil moisture at different depths in different times. Compared to uncovered fields, larger differences in soil moisture content occur at the depth above 60 cm. Straw mulching can evidently improve the moisture contents of the soil surface layer. If straw mulching is made from the beginning of winter to the wheat jointing stage, the soil moisture of mulched fields will well increase compared to uncovered fields. The soil water content within a 1 m soil layer in straw mulched wheat fields is in the order of 10 mm higher at the jointing stage of winter wheat than in uncovered fields. Yield increases of generally between 6 and 15% have been measured and water use efficiency increases of more than 20%, but the latter are generally between 12 and 16% on a multi-year basis.

The ecological effects of the practice on farmland include two aspects - water and fertilizer. From the perspective of water, as we have seen, the effects are to reduce soil evaporation, hence preserving its soil moisture, and to improve water use efficiency. In terms of fertilization, straw residues fertilize the soil after long-term physical effects and chemical decomposition, which is a long accumulative process and becomes tangible in the farmlands with multi-year straw mulching. The policy support in this capacity building in microclimate improvement was as in the former case. Further details are also in Stigter et al. (2008b).

IX. Forecasting fungus disease conditions for wolfberries (Liu Jing, China)

In studying the climatic zoning of high yielding and high quality wolfberry (*Lycium barbarum* L.) production, through experimental observations and investigations with wolfberry growers it was found that a fungus disease of wolfberry, Anthracnose ("black spot"), caused by the pathogen *Colletotrichum gloeosporioides* Penz, poses great threats to both wolfberry yield and quality. Although wolfberry is harvested throughout the growing season that the fruits appear, in the period mid-June to July inclusive the harvest is most abundant, with 70% or more being collected during that period. The determination and forecasting of suitable conditions for diseases is therefore most important during that period.

Quite often, summer thunderstorms are associated with wind. When swinging of wolfberry stalks scratch the fruits and other plant parts, the splashing of rain water facilitates infections and aggravates the disease. In a severe disease hit year, the percentage of diseased fruits leads to a loss of 50% in production, the market price dropping sharply due to inferior fruit quality. Meteorological conditions play a key role in the occurrence and development of this fungus disease.

The longer an above 90% relative humidity extends, during which the mean temperature becomes higher, the more invasive the fungus disease will be. When the mean air temperature is above 22°C, with maximum temperature exceeding 28°C, germination rates are high. Under such conditions, when both leaves and fruits are wet for over 6 hours, or when the rainfall is 5-10 mm, then a slight fungus disease is likely to occur. When at these temperature conditions the rainfall is above 10 mm or continues for more than 6 hours, the field transmission of the disease will be more significant. As the rainfall exceeds 20 mm or rain persists for more than 12 hours, still with favorable air temperature, it is more likely to witness a wider spread of the fungus decease in the fields. The infection rate may exceed 50%. If the rainfall is around 40 mm for that same duration criterion, the fungus disease of the wolfberry will break out epidemically. Now 50-80% of fruits will be affected or turn black.

With the above often determined from growth chamber research experiments, weather monitoring was carried out, forecasting and warning models were created, and comprehensive preventative and control techniques were identified. The severity of the epidemic disease is divided into 5 categories, according to field epidemic status, to identify the indicators of the fungus disease in development stages. Since 2006, these findings have been put into operational use, issuing trend forecasts and nowcasts. Early warnings about the occurrence of the fungus disease have been provided to decision makers. Further details are also in Stigter et al. (2008a). Policy support for this capacity building in disease forecasting was as in examples VII and VIII.

X. Early warning of low temperatures and less sunshine for crops in plastic greenhouses in winter (Li Chunqiang, China)

Plastic greenhouses have changed farming practices in northern China. They also tend to make full use of labor resources in rural areas, which is in line with China's conditions since farmers have greater economic returns with lower investments. No services for greenhouses did exist. The low temperature and sunshine conditions that limit production as well as more serious dangers needed an early warning system benefiting the vegetable growers using simple greenhouses.

Compared with a fully climate-controlled greenhouse, light, temperature, humidity and other meteorological elements in the simple plastic greenhouses are largely subject to outside weather conditions, and the man made interventions are limited. Therefore, plastic greenhouses in winter are characterized by weaker sunshine exposure, high humidity and poor ventilation. The indoor vegetables, in particular fruit vegetables have a relatively high demand for light and heat. If low temperature & insufficient sunshine (LTIS) persist for a longer period, the temperature in the greenhouse will drop too much, while the humidity is likely to increase too much, which will not meet the necessary environmental conditions required for vegetable growth.

Information dissemination of this service of the forecasting of days with less than 3 hours of sunshine and some weather disasters, including low temperatures, is to the government and the farmers through weather forecasts. The service delivery channels include meteorological websites and TV weather forecast programs for the public and telephone for farmers. Relevant warning information and service products about an adverse event are disseminated in a timely manner to the agricultural management bodies and for agricultural websites, then the agricultural authorities re-disseminate the information via internet, SMS etc., guiding farmers to prevent and mitigate the impacts of the event. An early warning consists of 2 components: (1) impact analysis of past meteorological conditions, and (2) weather forecasts and warnings including preventive advices.

So, finally there is the lesson, from Hebei and more generally, of the importance of simply using existing and improved general - and of course where possible special - weather forecasts and short range climate forecasts for providing the required information as an agrometeorological service. Further details are also in Stigter et al. (2008b). The policy support for this capacity building in a specific weather forecasting came again, as above in the other Chinese examples, from a Provincial Government Meteorological Service, with the approval of the China Meteorological Administration, Beijing.

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