# Operational Agrometeorological Services for Extension Needs and the Supportive Role of Agricultural Research

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## Abstract

The climatic and environmental resource base of crops plays a dominant role in their survival, growth, and development. Therefore, weather and climate, crops, other parts of the resource base, and crop/weather and crop/climate relations need the continuous attention of applied research. This helps not only to protect the resource base and sustain the quality and quantity of crop yields, but it also is a basis for the farmers' income. However, to make sense, the products of science as well as forecasts and advisories must increasingly be made available to assist the farmers, through operational agrometeorological services, which range from agroclimatological characterization to management of natural resources. To explain the actual scarcity of agrometeorological services, particularly in developing countries, Stigter developed a diagnostic and conceptual framework that pictures the generation and transfer of agrometeorological information from the existing support systems to its adaptation, dispersion, and teaching at the farm level. This framework lessens the confusion between the goals and means in generating agrometeorological services. Diagnosis of current agrometeorology practices shows a need for agrometeorology to arrive at on-farm agrometeorological services. This is illustrated with ample examples from an earlier defined list of such services. It is concluded that agrometeorological in-service education of extension intermediaries is essential to train farmers in field classes, improve their income, and protect the agricultural production environment from degradation. This ultimately materializes in down to earth and to the point agrometeorological services in well-defined farming systems.

## Introduction

Agricultural meteorology, as an accepted term, is only about 80 years old. The aim of agricultural meteorology is to make use of the science of meteorology in the interest of food production and its security. The first half of this period saw its development in the western world, Japan, India, and in China, where it had to be completely rebuilt since the 1980s (Stigter, 2002).

In the physical environment of plants, the components may be seen as a physically unified and dynamic system called Soil – Plant – Atmosphere – Continuum (SPAC). In this system, various physical processes occur continuously and interdependently and knowledge of these processes is the basic pre-requisite for understanding the behavior of plants in relation to their environment. Agricultural production can be maximized from the soil, if all agricultural operations are planned keeping in view the physical, meteorological, climatological, and hydrological properties in relation to the physical forces and conditions in the atmosphere at optimum dynamic equilibrium, under which seeds and plants survive and remain productive (Moharir, et al., 2003).

The world is witnessing shrinking land and water resources for agriculture, increasingly varying agroclimatic conditions, and spiraling population explosions. In this scenario, judicious management of soil, water, air and other natural resources, early warning and forecasting and prevention of degradation of environment assume paramount importance. Agricultural meteorology plays an important role in understanding the underlying processes of change in the SPAC, helps in recommending proper management practices, and assists in evolving strategies to keep crop production sustainable under changing conditions. However, there is a very slow progress in the direction of taking agrometeorological products to the end users. Many suitable research findings or products based on such findings are not at all transferred to the farmer's field through extension workers (Stigter, 1999). Therefore, it is necessary to train such intermediaries to make the products more client-friendly and more tuned to actual farmers' needs. This calls for identification of the farmer's field problems with agrometeorological components that pertain to agricultural practices to guide the science of agrometeorology in more operational use (Stigter, 2001 and 2003c). Ultimately field classes will be needed to train the end users.

**Stigter's Diagnostic and Conceptual Framework and Operational Agricultural Meteorology**

Agrometeorological services are defined here as all agrometeorological and climatological information that can be directly applied to improve or protect agricultural production (yield quality, quantity, and income obtained from yields) while protecting the agricultural resource base from degradation (Stigter, 2004).

The bottlenecks that appear in transfer of agrometeorological information through agrometeorological services are insufficient considerations of the actual conditions of the livelihood of farmers; and development of inappropriate support systems (Stigter, 2003b).

To overcome these bottlenecks, an "end to end" scheme in agrometeorology was developed by Stigter (Figure 1, e.g., Stigter, 2003c). It pictures the build-up and transfer of agrometeorological and agroclimatological information to the end users (farmers). It acts as a good guide for understanding the value of activities in the field of data, research, education/training/extension ("E, T & E"), and policies for the design of agrometeorological services to end users on an operational basis.

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A←------------ |-------------→   B   ← ------------ |--------------→   C
               |                                    |
               |                                    |
              E2                                   E1
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Figure 1. End to end scheme in agrometeorology

**A** = Sustainable livelihood systems.
**B** = Local adaptive strategies (knowledge pools based on traditional knowledge and indigenous technologies).
+ Contemporary knowledge pools (based on science and technology)
+ Appropriate policy environments (based on social concerns and environmental considerations, scientifically supported and operating through the market where appropriate).

**C** = Support systems to agrometeorological services:
Data + research + education/training/extension + Policies.
E1 = Agrometeorological Action Support Systems on Mitigating Impacts of Disasters.
E2 = Agrometeorological Services Supporting Actions of Producers.

In this scheme, in the so-called “C” domain, there are support systems such as data, research, “E, T & E”, and policies. These basic support systems are of a purely supportive nature. Activities of such kinds also exist in the so called “A” (livelihood of farmers) and “B” (initial and boundary conditions for problem solving) domains. The focal guiding activities are found in the $E_1$ and $E_2$ domains (see Figure 1 and below for detailed explanations). In these operational domains and activities, the data, research, “E, T & E”, and policies are actually used/carried out in action, not in support of unproven possibilities.

Across the globe, as of now, there is a lot of work in these basic agrometeorological support systems in the “C” domain. However, there is an absolute need for such basic scientific activities to selectively support the activities in $E_1$ action support systems and $E_2$ services. In reality, too many of the products of research lay idle and will never be used supportively. Even if they are used, they are playing too much of a guiding role in technology development, which these days should be guided by social concerns and environmental considerations (Stigter, 2003b).

The four ingredients of the support systems have been intentionally used in building Action Support Systems ($E_1$) to mitigate the impacts of disasters. Unfortunately, they have too often little to do with the real world of the livelihood of farmers (domain “A”). In this domain, the agrometeorological services should deliver support for the actions of actual producers. This support should in turn be carried out by the right mixture of the three components of the “B” domain containing the knowledge pools distinguished for use in the $E_2$ guidance and other related actions towards and in the “A” domain. From the above scheme, it can be inferred that to give more priority to the livelihood of farmers, the following issues must be considered in developing agrometeorological services:

- The local adaptive strategies of the farmers;
- Right choices in the use of contemporary science;
- The overwhelming effect of inappropriate policy environments;
- The social concerns and environmental considerations that are at stake in the “B” domain;
- The support from the focused $E_1$ guidance and the “C” domain; and,
- The understanding of what is actually possible in $E_2$ guidance and of the very conditions in the ‘A’ domain, the livelihood of farmers.

## Examples of Operational Agrometeorological Services for Extension Needs and the Supporting Role of Agricultural Research

Agrometeorological research as a support system particularly needs constant regional, national, and local prioritization. Based on the above scheme, the overall priorities for agrometeorological services, in many places, that were identified during a Commission for Agricultural Meteorology (CAgM) workshop in Accra (Stigter et al., 2000), a possible list of agrometeorological services (e.g., Stigter, 2004) is exemplified below. Ultimately, end users have to be involved in the development of and have to be trained in field classes in the use of successful agrometeorological services.

*The products of agrometeorological characterization, obtained with whatever methodologies.*

Murthy (1995) defined agroclimate as the combined influence of climatic elements that make possible the cultivation of crops. As the climatic characterization is meant for judicious crop planning and management, the information generated should include length of possible cropping season, distribution of rainfall, nature of soil, evaporative demand, water availability periods, etc., of the region. A hot-season crop like sorghum, which can withstand temperatures ranging from 15°C to 40°C, performs well if water is not a severe constraint. On the other hand, regions where a mean 10-day rainfall of more than 30 millimeters (mm) is only available continuously for just 30 to 40 days are highly drought prone. For example, scientists in India advised the farmers that, under such conditions, they should grow either grasses or fodder for animals. Similarly, absence of rain continuously for 10 days necessitates soil moisture conservation techniques. Comparably, very local information on water deficiency obtained from local water balance computations were used to delineate areas and seasons with deficiency, which in turn helped to develop the probable amount of supplementary irrigation needed for recharging the soil at any given period.

All the above information and recommendations are $E_1$ research support systems (Figure 1) with good intentions. However, if agrometeorologists develop understandable maps depicting the above results on a large scale with a known accuracy, showing the vulnerability of regions for related disasters, then all of them become $E_2$ services. The same applies to any further work to get that information in a form with which extension workers can assist farmers at the field level. Only such services make a difference in the livelihood of farmers, no matter whether the scientists develop maps in a simple way or through GIS.

*Advice on above-ground and below-ground microclimate management or manipulation, such as shading, wind protection, mulching, other surface modification, drying, storage, or frost protection.*

Scientists have developed shelterbelts to protect crops and soils in different farming systems under the prevailing conditions of several regions. However, only appropriate design rules drawn from this supportive research form the actual agrometeorological services to the farmers (e.g., Stigter, et al., 1989). Two case studies follow.

In Yambawa, north of Kano in Nigeria, wind erosion coupled with wind-blown sand causes wind-driven desertification. The hot dry winds accompanied by decreasing rainfall forced the farmers to diminish crop production. A solution was found with a good intention of providing relief to the farmers through shelterbelts (Onyewotu, et. al., 2003), but it was determined from behind a desk. No pilot project had been planned; no knowledge of wind protection had been applied; and no participation of farmers in detailing the solution (choice of trees, planting pattern) had been solicited. The wrong tools were applied in analyzing the multiple shelterbelts for crop microclimate.

Supportive research found that perpendicular to the wind, the distances between belts should have been less than 100 meters (m), not between 110 and 300 m. This resulted in insufficient protection from hot winds. The expected high millet yields after the application of root pruning appeared to be much too small in the leeward protected areas. Only after proper design rules and alternatives had been derived were actual agrometeorological services partly applied.

Contrary to the above example, design rules as $E_2$ service were developed for traditional subsistence and small commercial farmers in the central clay plain of Sudan. “Pit storage” (storing grains in the underground for longer duration for food security) of annual production of sorghum in the cracking clay soils of the region helps the farmers in self-sufficiency of food throughout the year. This also helps in getting better returns as the farmers can market their grains when the prices are high. Partly based on farmer innovations, agrometeorologists and allied scientists, through their supportive research recommended that wide shallow pits using thick chaff linings and wider above ground soil caps should be used for longer duration of storage of sorghum grains (Abdalla, et al., 2002).

Advisories can be based on the outcome of response farming exercises, from sowing window to harvesting time, using climatic variability data and statistics of recent past or simple on-line agrometeorological information. All agricultural activities from pre-sowing to post-harvest are influenced by weather. So, weather-based advisories to the farmers help them in day-to-day agricultural operations well in advance. This in turn helps to mitigate the adverse impact of weather. Response farming, a method of identifying and quantifying the seasonal rainfall variability to address the risks of the farmers at field level, is a classical example of such advisories (e.g., Stigter 2002). The hypothesis is that the solutions to farming problems may be found by improved forecasting of expected rainfall behavior in the cropping season(s). Response farming also means adapting crops to the ongoing rainy season by guidance of agronomic operations, using experiences of the past, preferably from interpretations of meteorological rainfall records, with support from traditional expert knowledge where available.

An example of research support is Ian Stewart's search for and application of forecasting some patterns of rainy seasons in Kenya, which made it possible to design advice on lowering planting density by thinning or adding fertilizer as side-dressing to improve the efficiency of resource use by the farmers.

*Establishing measures to reduce the impacts and mitigate the consequences of weather and climate related natural disasters for agricultural production.*

Much literature exists on the damage that natural disasters do to agriculture but preparedness and the related supportive research leave very much to be desired (e.g., Stigter, et al., 2003b). However, sometimes agrometeorological services have been developed from research. When temperatures at night fall below freezing point during springtime (in association with cold waves) there will be frost injury in orchards. The low temperatures irreversibly damage the flowers, and the harvest of fruits in autumn will suffer. If the occurrence of frost is well forecasted, it is good to advise sprinkler irrigation of the flowers during the previous day. Spraying the flowers with water prevents them from freezing and the blossom is safe and so are the future fruits.

*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.*

Murthy (1995) defined agricultural drought as a situation in which crops fail to mature due to insufficiency of soil moisture. Drought monitoring in case of field crops can be done using the relationship between water use and productivity. Several methods are available in literature for establishing the water use and productivity of crops. The Water Requirement Satisfaction Index (WRSI) of Frere and Popov (1979) indicates in percentage the extent to which the water requirements of an annual crop have been satisfied in a cumulative way at any stage of its growing period. The index at the end of the growing season will reflect the cumulative stress endured by the crop through excess and deficits of water and is closely related to the final yield of the crop. Yet, this is an $E_1$ support system because advice to the farmer is lacking.

There are several ways of monitoring and forecasting drought but these exercises should always be accompanied by recommendations developed in the "B" domain, like growing a short-duration crop, thinning, in-situ moisture conservation, etc., as agrometeorological services. As long as farmers do not get validated benefits out of the above advice, monitoring and forecasts remain $E_1$ support systems only.

*Climate predictions and forecasts and meteorological forecasts for agriculture and related activities, on a variety of time scales, from years to seasons, and from a variety of sources.*

A good climate prediction is not always a good agrometeorological service. Not only the skills of the forecast count but also the absorption capacity of the target groups matter a lot. This is well illustrated in the following case study (Lemos, et al., 2002).

The seasonal climate forecasts in Cear'a, N-E Brazil, for maize/bean/manioc growers, on drought were found to be a disaster. An emerging technology "was appropriated and pressed into service of a policy making apparatus designed to reduce the impacts of severe droughts." Policy-makers started to exaggerate the potential usefulness of the science product, "therefore creating a situation of cultural dissonance between science and local knowledge and belief systems that quickly eroded the value of the information" (Lemos, et al., 2002). The scientific product, a typical $E_1$ action support system, which did not have the right mix in the "B" domain, was not used to lead to useful $E_2$ agrometeorological services. Due to their particularly vulnerable socio-economic conditions, the farmers were unable to respond to raw climate predictions, irrespective of the quality and the precision of the forecasts.

*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 livelihood of the farmers.*

Murthy (2002) defines climate change as "any long term substantial deviation from present climate because of variations in weather and climatic elements." If supportive scientists develop with the farmers an improvement of an already existing adaptation to increasing climate variability, then the new product may be called an agrometeorological service when the policy environment is conducive to such change. In this direction two examples from India show what is basically possible to make a positive difference in the livelihood of farmers.

The first is the use of the Southern Oscillation Index (SOI) to advise farmers on growing either cotton or peanuts in parts of India. In years with positive SOI, peanuts outperformed cotton in 70 percent of years and in negative SOI years there was only small advantage in 40 percent of years. So, if farmers grow cotton in SOI negative years, the above supportive research produced an $E_2$ service.

The second example is potential advice on the seasonal rainfall probability for profitably growing of peanuts in parts of India. The supportive research results indicate that if the seasonal rainfall (July to December) is >50 centimeters (cm), the yield probability of >1.5 t/ha is 50 percent and the probability of yields <0.7 t/ha is zero. Therefore, prediction of rainfall "greater than" or "less than" 50 cm would be extremely helpful to the farmers.

However, it appears that in 87 percent of El Niño years the seasonal rainfall was <50 cm, but of the 58 years with rainfall <50 cm, only 21 were El Niño years. This shows the problems of supportive research. Still, a better forecast would be an $E_1$ activity, but could be made into an $E_2$ service if this information was reliably explained as to probabilities, and was made available in time and in a way that local farmers can absorb, and if other agrometeorological information and other inputs for crop production could be simultaneously supplied as per the required schedule.

*Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases and/or advice on countervailing measures.*

There is a considerable loss in the production of food grains due to occurrence of pests and diseases. Supportive studies based on the relationship between the micro/macro climate and origin, multiplication, spread, and intensity of diseases and pests may be useful to understand the environmental conditions that are congenial for their development. In supportive research Nagarajan and Hardev Singh (1976) proposed a method for predicting wheat stem rust appearance in South India based on the occurrence of synoptic conditions likely to lead to the transport deposition of spores. Even earlier, Rainey (1963) supportively identified synoptic situations associated with the migration of desert locusts. Chakravarthy and Gautam (2002) developed a forewarning theory, which has a potential as an indicator of mustard aphid population build up. Using simple parameters, this can be done as early as one month in advance. This may enable the farmers to be ready with necessary tools to combat the pest problem, if advised accordingly. Such supportive studies in the "C" domain may not have any operational utility unless they pass the "B" domain process of using the right mix of the three pools of knowledge and become an $E_2$ service in the "A" domain.

*Advise on measures reducing the contributions of agriculture production to global warming.*

The major environmental problem today is global warming, which is due to accumulation of several gases causing greenhouse effects and depletion of the ozone layer in stratosphere; finally also affecting agricultural production. However, contributions to reducing contributions to global warming should be asked from developing countries particularly in combination with measures that improve efficiencies of resource use and the health of their populations.

For example the wetland rice fields are a major source of atmospheric methane. The following measures would pertain: prevention of submergence of rice fields wherever feasible without affecting the rice productivity; increased adoption of direct seeding instead of transplanting; crop diversification in rice-based cropping systems; water management by intermittent drying and mid-season drainage in controlled water situations; growing rice cultivars having traits with low methane emission potential; use of sulfate containing fertilizer; minimizing of soil disturbance during the growing season to reduce the escape of entrapped methane; use of properly composted organic amendments. Several of these measures serve resource-use efficiency purposes.

*Proposing means of direct agrometeorological assistance to manage natural resources for development of sustainable farming systems.*

When for example knowledge from field experimentation is utilized in supportive crop simulation models, gaps between actual, attainable, and potential yield for a given environment can be determined. Also, some opportunities for yield improvement, for example through improved sowing windows, can be asserted by using strong agrometeorological sub-routines. However, validating the predictive power of a model for the management of the natural resource base is essential for using it at an operational level. Modeling can be of immense use in high input agriculture. However, operational use of the model means making predictions on the performance of the crop and suggesting ways of managing which lead to a sound basis for the final stages of field testing prior to advising farmers ($E_1$ support services) or to direct formulation of recommendations ($E_2$ services). However, modeling socio-economic aspects is still too cumbersome.

## Conclusions

- The consequences of increasing climate variability/change make it necessary to urgently strengthen participatory extension in the field of agrometeorology and climatology;
- Intermediaries between general agrometeorological advisories/forecasts and agrometeorological services have to be trained for increased preparedness for new or worsening problems of farming systems, caused by climate disasters (Stigter, 2003a);
- Farmers, extension intermediaries, and agrometeorologists should much better understand needs, possibilities, limitations, and realities for/of agrometeorological services in well-defined farming systems. This is essential for successful development and implementation of actual operational agrometeorological services (Stigter, et al., 2003a);
- An independent national agrometeorological data bank has to be established in every country and liberal policies should be adopted for supply of trustable agricultural and meteorological data to the research (and extension) institutions involved in agrometeorological research (Ramana Rao,1988);
- A database of sound and dependable supportive research results must be developed by agrometeorologists in various application fields. Ongoing research programs have to be recast by much more functionally looking into the problems and priorities for developing and organizing operational agrometeorological services for specific farming systems (examples in this paper);
- A number of in-service training programs for extension intermediaries have to be established, by and for agrometeorologists, to make them better aware of the actual needs of the farmers, with agrometeorological components, in different farming systems. Training also is needed on how to use agrometeorological products together with knowledge from neighboring disciplines for the benefits of those farmers. Their successes, failures, and experiences will have to be brought back into the curricula of agrometeorological personnel of the NMHSs and into those at vocational schools and universities, to enlighten the classical training in agrometeorology and strengthen its usefulness (Stigter, 2003a); and,
- End users must be trained accordingly in appropriately organized field classes.

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