USING TRADITIONAL METHODS AND INDIGENOUS TECHNOLOGIES FOR COPING WITH CLIMATE VARIABILITY

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Abstract. In agrometeorology and management of meteorology related natural resources, many traditional methods and indigenous technologies are still in use or being revived for managing low external inputs sustainable agriculture (LEISA) under conditions of climate variability. This paper starts with the introduction of an "end-to-end" climate information build up and transfer system in agrometeorology, in which the use of such methods and technologies must be seen to operate. It then reviews the options that LEISA farmers have in risk management of agrometeorological and agroclimatological calamities. This is based on the role that the pertinent meteorological/climatological parameters and phenomena play as limiting factors in agricultural production and the expectations on their variability. Subsequently, local case studies are given as examples of preparedness strategies to cope with i). variable water/moisture flows, including mechanical impacts of rain and/or hail, ii). variable temperature and heat flows, including fires, and iii). fitting cropping periods to the varying seasons, everywhere including related phenomena as appropriate. The paper ends with a series of important additional considerations without which the indicated strategies cannot be successful on a larger scale and in the long run.

1. Introduction

In a recent review of agrometeorology in tropical Africa, Olufayo et al. (1998) stated that consequences of climate variability show themselves at any time as the effects of the accumulated weather in the current growing season compared to those of the same period in previous years. There are countless farming communities which managed to survive and, in some cases, even to thrive by exploiting natural resource bases, which their forebears have used for generations (Reijntjes et al., 1992). Through a process of innovation and adaptation, traditional farmers have developed numerous different indigenous farming systems finely tuned to many aspects of their environment (LEISA, 2000). Such risk management strategies were in response to, among others, the limiting conditions of varying climate. Over the microclimate they nevertheless exercised significant control, as numerous review publications have indicated (e.g. Smith, 1972; Wilken, 1972; Bunting, 1975; Stigter, 1988, 1994; Stigter et al., 1992). However, new operational services in agricultural meteorology are badly needed for decision making in risk management for

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specific on-farm conditions. These agricultural environments of peasants in non-industrialized regions are now endangered by new and expanding hazards that rapidly change the living conditions in many places in the tropics and sub-tropics (e.g. Stigter and Baldy, 1993; Baldy and Stigter, 1997; Blench and Marriage, 1998).

Among much other literature, the IPCC reports, from many sources that they used, have convincingly reviewed the scenarios. Increasing climate variability, resulting in more frequent and more serious extreme meteorological and climatological events, will be a factor with which all farming systems will have to cope. Salinger (2004) has unmistakably concluded that we are heading for hard times in agriculture and forestry. From Africa (e.g. Mungai and Stigter, 1993; Stigter, 1995; Baldy and Stigter, 1997) to Latin America (e.g. Wilken, 1987) and different parts of Asia (e.g. Anonymous, 2001; Luo, 2001; Manton, 2001), those working in rural areas have become convinced of two essential issues. Firstly, traditional knowledge, indigenous practices and identified local innovations (e.g. LEISA, 2000, 2001) contain valuable information that should be used as a basis for improved farming systems practices to cope with the necessary changes in risk management. Secondly, contemporary science and new methodologies and technologies should, also in agrometeorology, be guided by appropriate policies, that themselves need a scientific basis and a humane socio-economic basis. They should be locally applied to develop agrometeorological services to assist in the risk management transformations needed (e.g. Smith, 1972; ILEIA, 1995; Stigter, 1999; Salinger et al., 2000; Stigter et al., 2000). Figure 1 reviews this systematically.

In their classic treatise, Brokensha et al. (1980) refuse to define indigenous knowledge and point to the case studies collected to describe it. Fifteen years later Warren et al. (1995) call it "the local knowledge that is unique to a given culture or society" and contrast it with the international knowledge system, which is generated through the global network of universities and research institutes, that we have called contemporary knowledge in Figure 1. Our context of LEISA farmers, this way defines traditional knowledge and indigenous technologies, also when, as may be expected, components of that knowledge have found their way into higher input and even high-tech growing systems. Local innovations are knowledge and technologies empirically generated by the, in this case LEISA, cultures and societies from within their present farming systems (LEISA, 2000). In line with the stewardship advocated by Houghton (1997) and the highest resilience emphasized by LEISA (2001), to the role of science applies the paradigm change worded by Norse and Tschirley (2000): technological change should no longer be driven by science but by environmental objectives and social concerns, like farmer innovations, operating through the market where appropriate. It is these policy environments that should guide the knowledge pools towards operational agrometeorological services for farm management decisions (Stigter 2002a, 2002b).

This paper exemplifies the valuable local knowledge of preparedness strategies. It wants to work with case studies in which indigenously developed technologies

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

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A   <-------|------->   B   <------ |------->   C
            |                       |
            |                       |
            E2                      E1
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E1 = Agrometeorological Action Support Systems on Mitigating Impacts of Disasters

E2 = Agrometeorological Services Supporting Actions of Producers

Figure 1. Relations between the three activity domains (A, B and C) defined, guided by agrometeorological action support systems on mitigating impacts of disasters (E1) and agrometeorological services supporting actions of producers (E2). This "end-to-end" system in agrometeorology, for transfer of climatological information, combines earlier ideas in Stigter et al. (2000), Norse and Tschirley (2000), Shumba (2001) and Stigter (2002a, b).

are used for agrometeorological services in risk management, illustrating this new paradigm in coping with climate variability. The context of this must be that particularly over the last two decades or so, developments in the field of meteorology, climatology and the environment as well as socio-economic changes occurred much faster than new adapted and innovative agrometeorological services could be established. This is due to difficulties in making interdisciplinary knowledge operational for sustainable agriculture in developing countries and to problems in having new information absorbed and applied in rural areas, against the background of a deteriorating infrastructure (Stigter, 2001). It is now widely accepted that only where households are fully incorporated in all phases and aspects of development processes, may future innovative services in agrometeorology make any difference for the income of LEISA farmers (e.g. Das, 2001; Norman, 2001).

We deal in an end-to-end system for build up and transfer of climate information in agrometeorology with the relations between sustainable livelihood systems (domain A in Figure 1), pools of knowledge allowing useful strategies towards agrometeorological services (domain B in Figure 1), and basic support systems (domain C in Figure 1) (Stigter et al., 2000; Norse and Tschirley, 2000; Shumba, 2001; Stigter 2002a; 2002b). After all, the good intentions of the agrometeorological action support systems on mitigating impacts of disasters that we established so far (E1 in Figure 1) did not lead to sufficient operational agrometeorological services to support farm management decisions (E2 in Figure 1). In LEISA, traditional methods, indigenous technologies and local innovations still have an important role to play. This shows the context of the approach in this paper.

2. Options that LEISA Farmers have

We do no longer have to argue in favour of an increase of necessary inputs. It has been generally accepted that without such improvements of i. soil fertility and other soil conditions that are basic to sustainable farming systems, ii. soil moisture conditions, iii. varieties, crop combinations and rotations and iv. land husbandry as a whole, there is no future for successful LEISA farming (e.g. Reijntjes et al., 1992; Shaxson et al., 1997; Olufayo et al., 1998). However, such improvements must be seen within their socio-economic context. The options that farmers have, to cope with (increasing) climate variability, apply to their actual conditions, which vary greatly geographically and agronomically.

Of the basic atmospheric conditions that limit agricultural outputs, radiation, CO_2 and wind (flow of momentum) are changing. They will in the existing scenarios continue to change measurably over time, but their variability will not, peak winds during calamities excepted. To cope with this general variability, the LEISA farmer will generally not have to take precautions different from those that have been or could have been taken in the recent past and at present. The options defined by Stigter (e.g. 1988, 1994), for microclimate improvement by management and manipulation of radiation and impacts of (consequences of) wind, including gas exchanges other than water vapour, also remain virtually the same. This is not true for such options coping with moisture and vapour flows, temperature and heat flows, mechanical impacts of rain and/or hail and technologies to fit cropping periods to the seasons. It is, therefore, also not true for the phenomena due to (mitigations of) drought, flood, water erosion and other related matters, such as those regarding desertification, forest and bush fires, pests and diseases. This differentiation is largely due to the role of these phenomena as limiting factors in agricultural and forest production and the expectations on their future variability. There may always be local exceptions to the above distinctions, such as in a particular variation in wind direction reported to be used in traditional forecasting of the strength of the monsoon (Anonymous, 2001).

The time scale for (new) options for farmers to cope with (increasing) climate variability may vary from several seasons to the ongoing (part of a) season. An example of the first end of the scale was given by Bakheit et al. (2001) and Stigter

(2002a, b), using work of Abdalla et al. (2002a). The Sudanese government was advised on a forecasted climate change scenario in which longer sequences of dry years would be intermitted with longer periods of wet growing seasons. The government proposed research on improved underground storage of sorghum, for longer storage periods. On a large scale, as practised in strategic grain reserves by the government (up to 300 tonnes), as well as on the small scale of mainly subsistence and other small farmers (2–10 tonnes). It was found from a questionnaire that the latter farmers experimented with pit linings to insulate the grain from the soil (Abdalla et al., 2001) and with shallower pits (Abdalla et al, 2002b). These innovations with respect to traditional methods were quantified and optimised. Wide surface caps were added from research experience. This way improved traditional underground grain storage microclimate assisted to cope with consequences of forecasted changes in the distribution of bad and good rainy seasons.

The shorter time context is exemplified by Anonymous (2001) in the proposal to use traditional knowledge in determination of the start of the growing season in India. The flowering peak of blooming of the *Cassia fistula* tree appears to do an admirable job in Gujarat of predicting whether the monsoon will come early or late. As these examples are dealing with traditional farming systems or more recently derived innovative indigenous knowledge, they fit this paper. However, for example, Ati et al. (2002) proposed to determine the start of the growing season on-line from soil moisture observations. This could replace a traditional method, based on the occurrence of the Ramadan, that in retrospect appeared inferior to scientific methods and kept yields considerably lower at all levels of fertilizing (Onyewotu et al., 1998). Probabilistic forecasting, through the use of the Southern Oscillation Index, may well be able to compete with the above-mentioned traditional knowledge in India (CLIMAG, in WMO, 2002). This shows that no generalized statements may be used on the value of traditional methods and that local case studies have to illustrate the usefulness of options. Organizing timely availability of the information and services, in the right form, then becomes a decisive factor in being able to use them in risk management decisions.

The options remaining valid with respect to wind have recently been exemplified for smallholder agroforestry by Stigter et al. (2001, 2002), while those of radiation are particularly scattered throughout the intercropping literature (e.g. Stigter and Baldy, 1993; Stigter, 1994; Baldy and Stigter, 1997). A wind example is the use of trees to combat desertification and limit damage by dry air through mitigation of wind speeds and turbulence, contributing to resource and crop protection (Onyewotu et al., 1998; Stigter et al., 2002; Onyewotu et al., 2003). Another is the reduction of wind erosion by keeping stubble in winter from summer intercropping belts on sloping land in Inner Mongolia (Zheng, internal publications, 1999; An and Tuo, 2001). Radiation examples may be found in i. shade protection; ii. pruning of trees in all kinds of agroforestry systems and iii. other intercropping systems aiming at resource sharing (Stigter and Baldy, 1993). Note that these risk management examples deal more with mitigation of the parameter itself and not with the climatological variability of that parameter. However, these short examples illustrate the importance of modifying a parameter, this way influencing the range of its variability. It should, in addition, also be stressed that these examples may play a key role in transfer of climate information for risk management strategies and agrometeorological services towards sustainability of LEISA farming systems with improving inputs, and therefore in their stability.

3. What LEISA Farmers do and may do

Climate variability and related disasters can be mitigated by temporary or permanent protective measures or by avoidance strategies that try to escape the peak values or their consequences. These are all aspects of preparedness strategies. We have indicated above that i. heavy moisture flows or the lack of water, ii. changing heat flows and related temperatures, iii. cropping seasons' climate distributions are the meteorological/climatological factors we should particularly deal with in this paper on traditional knowledge and indigenous technologies that mitigate consequences of climate variability in LEISA farming systems.

3.1. WATER

The IPCC reports clearly indicate rainfall variability and related disasters as the single most determining factor endangering agricultural production in developing countries. Drought being already a serious threat, indications for longer dry spells in rainy seasons and longer sequences or higher frequencies of abnormal rainfall seasons, with respect to total rainfall and rainfall distribution, make ways of coping with drought situations even more important.

As early as 1986 the FAO/UNEP/UNESCO/WMO Interagency Group on Agricultural Biometeorology had Orev publishing his "*Practical Handbook on Desert Range Improvement Techniques*", containing two long chapters devoted to the problems of mobilizing, managing and utilizing water resources for local technicians in local agro-pastoral populations in the drier parts of Africa, starting from local experience. Most recently, Das (2001) has reviewed examples in which prosperity of districts and villages in India were directly related to preservation of traditional water harvesting methods and technologies of the use of underground water. A related technology of which also IPCC advocates more intensive use is that of water impoundment, surface storage for later use. This is for example contemplated in Indonesia to make the country again self-sufficient in rice production (Syarifudin Karama, personal communication, 1997), which is at present becoming increasingly lower (Paltridge and Ma'shum, 2002), and in El Salvador after the most recent ENSO triggered drought (Zimmerman, 2001). In Sri Lanka the traditional so called "bethma" practice combines such reservoirs with temporary land redistribution and sometimes field rotation, and attempts are made to revitalise this old practice (MOST/CIRAN, running database (1)).

In Niger, traditional planting pits were improved by making them into water collecting reservoirs imitating part of a soil improvement technology traditionally used in other parts of the country and in Burkina Faso (MOST/CIRAN, running database (2)). From Burkina Faso, it has most recently been reported that villages that adopted land reclamation techniques such as this pitting through crusted soils, filling the pits with manure and water, have seen crop yields rise by 60%, while villages that did not adopt these techniques realized much smaller gains in crop yields under very recent rainfall increases (Reij, cited in Katz, 2002). In north Nigeria small pits in sandy soil are filled with manure for keeping transplanted tree seedlings wet after the first rains. This is tried in China by stony structures in pits, diminishing soil evaporation. Permaculture, water harvesting and infiltration pits, together with the use of drought tolerant crops, have been more recently extended in Zimbabwe, particularly by women, with the help of NGOs, in reply to the recurrent droughts (Shumba, 2001). In semi-arid Nigeria water-harvesting constructions with gutters and bonds are traditionally used around Cassava plots. Again for West Africa, Slikkerveer (1999) mentions a project case study of the successful re-introduction of indigenous "demi-lunes" for better water harvesting. This method was also successfully used in Sudan by the TTMI-project for tree establishment in an arid area near the White Nile (Adil Ahmed Abdalla, personal communication). The earlier example in Niger and these latter two examples further demonstrate the significance of integration of indigenous knowledge and practices in development co-operation projects aiming at increasing resilience (e.g. LEISA, 2001; Stigter and Ng'ang'a, 2001).

Traditional methods and farmer innovations of using occult precipitation under very dry conditions have been dealt with by Acosta Baladon (1995). Further evidence that many of the current traditional adaptation strategies with agrometeorological components also hold for the situations of increasing climate variability is the following quotation from Lin Erda in Zheng et al. (2001) on future measures in China:

> "the response strategies include changing the land topography to reduce run off, improve water uptake and reduce wind erosion, introducing artificial systems to improve water availability and to control soil erosion, changing farming practices to conserve soil moisture and nutrients, changing farm operations timing to fit new climatic conditions and using different crops or varieties to match variations in the water supply and temperature conditions. (...) In the course of time new technologies may have to be developed to cope with anticipated impacts and to reduce the costs of adaptation".

It is of course not always a(n) (increasing) variability of climate leading to innovative water use. Changes in cultivation due to population pressure, such as being forced to use sloping land prone to water erosion (Ong et al., 1996; Zheng and Tuo, 2000), as well as income and market considerations have also led to extending or replacing old practices and using new practices that at the same time increase the resilience of the farming systems (Tchawa, 2000) and protection against consequences of drought (Nasr et al., 2000).

As to floods, the technological literature is less abundant and the solutions have most often little to do with agrometeorology as such. For example, traditional drainage ditches and tunnels have been reported from wheat fields in China (Cheng Yanian, personal communication, 2000). In some cases evaporation and occasionally soil conservation and shading by water absorbing trees play a role. Mitigation by reforestation is an often-mentioned aspect (e.g. MOST/CIRAN, running database (3)). However, preparedness and post-disaster measures are more often referred to because, large infrastructural measures apart, there are few ways to counteract serious floods (e.g. Berg et al., 2001).

As to mechanical impacts of rain and hail, although they are forecasted by IPCC to increase in several regions during peak rainfall, we have not found any examples in the literature dealing with increasing protection attempts. The usual protection of crops and soil by the cover from trees, bushes, crops, crop residues left standing, and grass cover and/or mulching will be increasingly necessary, where these problems of mechanical damage of crops and soil are most serious, depending on the specific crops and soils concerned (Stigter, 1994). Classic work from China reviews various traditional adaptations after serious hail damage, assisting plant recovering, through management and compensation measures, or planting follow-up crops in accordance with the length of the remaining growing season (SAAS, 1977). Rivero Vega (2002) reviews other evidence on traditional adaptation measures for hail protection. Such technologies are applicable elsewhere when such damages are increasing (like in India: V.R.K. Murthy, 2002).

3.2. HEAT

Even small changes in the frequency of extreme temperature events may have disproportionate effects. Salinger et al. (2000) mention the life cycle of perennial plants and the stability of forage supplies as well as the balance between temperature and sub-tropical species as examples. It appears that response farming, as we will deal with it in Section 3.3, should not only be considered with respect to fitting the cropping seasons to variable rainfall patterns, but also for fitting it to variable temperature patterns (Van Viet, 2001). This shows that heat is another important factor to be considered in strategies to cope with climate variability. In this case study (Van Viet, 2001), using seasonal temperature forecasting, recommendations could be given on planting date or a combination of planting date and variety, to make sure that rice was flowering in decades for which the required optimal temperatures had been forecasted. Contemporary scientific knowledge has taken over from traditional knowledge here. For example, the detailed knowledge available, as reviewed, on the influence of temperature, temperature extremes and temperature distributions on growth, development and yield of rice (Salinger et al., 1997) makes this possible. Temperature may be involved in flowering peaks of plants used as a traditional forecast for monsoon arrival (Anonymous, 2001).

Farmers near Beijing adapted their sayings on the best seeding time since the 1980s, because of the warming of which they observe the agronomical consequences. So also traditional weather lore may change. Where temperature is a limiting factor to photosynthesis, traditional farmers may react to cooling/warming by changing their cropping system. This is exemplified by the North China Plain, where originally a change from double cropping to more traditional intercropping of early maize with late wheat took place. In southern parts intercropping, that gave higher degree-days for maize, was after a decade again replaced by double cropping, while in cooler mountainous areas and further North the intercropping was kept (Zheng et al., internal publications in the 1990s). However, in many other cases the protection will again very likely not change with any increase in variability of temperature. We are then back to the relevant examples of microclimate management and manipulation (Stigter, 1988, 1994), among which there is the classic example of too severe heat flow/temperature modification, by traditional grass mulching against water erosion, leading to subsequent death of young tea (Othieno et al., 1985). Another example of this kind is the traditional furrow sowing of winter wheat in northern China, giving stronger seedlings less suffering from winter damage, due to more soil moisture and higher temperatures in the furrows (Zheng et al., internal publications in the 1980s).

Protection of crops against hot air by shelterbelts was reported by Onyewotu et al. (1998) for reclaiming a desertified area under highly variable climate conditions (Onyewotu et al., 2003). However, it is indeed in traditional parkland agroforestry and other stabilising intensive management of scattered or clumped or alleyed trees that such risk management may be most efficiently found when risks increase (Arnold and Dewees, 1998; Boffa, 1999; Mungai et al., 2001; Onyewotu et al., 2003). It is generally accepted that the weather conditions that create the infamous drought and flammable forests under Indonesian conditions are quite natural, even when their frequency and intensity have increased. However, the factors that have turned this into a disaster, are man-made because most fires are deliberately lit for various reasons. They are due to deliberate policies of non-preparedness and inaction in the face of warnings of extreme fire dangers (Byron and Shepherd, 1998). That is why the appropriate policy environments occur in the B Domain in Figure 1. With the appropriate policies in place, preparedness using meteorological forecasts for grading fire danger has been shown to be a good solution under highly varying conditions (WMO, 1993).

3.3. FITTING CROPPING PERIODS TO THE VARYING SEASONS

The oldest way of coping with climate variability is trying to fit cropping to the ongoing season, using in risk management any possible indigenous forecasts on its behaviour or adapting to what is experienced in the ongoing season. Flexibility and resilience of farming systems with respect to rates of change is a recurrent factor in such attempts. There are ample examples of permanent, slow and fast traditional adaptations to seasonal variability for reasons of risk management and food security (e.g. Bunting, 1975; Stewart, 1988; Blench, 1999; Clemens and Nashrullah, 1999; Gadgil et al., 2000). In fact, these adaptations may be seen as the oldest examples of response farming in the most direct meaning of the words. However, there are no expectations of improvement of these traditional "fitting" methods per se under the presently fast changing conditions. Their blending with more scientific meteorological/climatological and agronomical/breeding approaches appears the only way forwards (Blench, 1999; Gadgil et al., 2000), as also implied by the end-to-end scheme of Figure 1.

Stewart (1988, 1991) defined response farming in a more limited way, with respect to adapting cropping to the ongoing rainy season by guidance of agronomical operations, using experiences of the past, preferably from interpretations of meteorological rainfall records with support from traditional expert knowledge where available. Given the indications for increasing variability and change of the climate in terms of rainfall, this will have to be adapted to those new conditions, limiting the period in the past over which the experience can be used (Ati et al., 2002). In agrometeorology, pilot projects with the use of on-line agrometeorological information for farmers to respond to, successfully exist already for two decades in West Africa (e.g. Traore et al., 1992; Diarra, 2001). When such changes in definitions of response farming are accepted, it is only a little step to include other parameters like temperature, a possibility earlier mentioned above in Section 3.2, due to better probabilistic seasonal forecasting techniques (Van Viet, 2001).

The situation described above also has another policies related face. Blench and Marriage (1998) have noted that in rain-fed farming areas of eastern and southern Africa, governments and development projects have encouraged high-input, high-risk strategies such as planting hybrid maize instead of sorghum and millet. This, although long experience of uncertainty about weather patterns had induced farmers to develop complex cultivar mixtures to ensure yields under all conditions. The effects of the prolonged drought of the early nineties could have been less, if the risks had been spread across a range of crops with greater tolerance of low-rainfall regimes, as that had been traditionally done. In another example, the dominance of a few seed companies combined with commercial pressure on farmers and an extremely negative attitude to "old" crops and open-pollinated varieties, as well as the replacement of many traditional livestock breeds with "modern" breeds, has massively increased small farmers' vulnerability to climate shock events. Because the high risks under adverse conditions are more important for poor farmers than the opportunities of better years, here the right policy environment is again surfacing as a necessary condition for services towards sustainable livelihood systems (Blench and Marriage, 1998).

In an even more recent paper, Blench (1999) has noted that multi-lateral agencies are urging that climate forecasts be made available to small-scale farmers. Disaster preparedness strategies, both of governments and NGOs, have begun to take account of such forecasts, and there is considerable interest in assigning them an economic value. However, field studies of the impact of recent forecasts in southern Africa suggest that there is a considerable gap between the information needed by small-scale farmers and that provided by the meteorological services (Blench, 1999). This was confirmed by investigating the role of intermediaries such as Agricultural Demonstrators in Botswana (Stigter, 2002b) and Provincial Agrometeorologists in Vietnam (Stigter, 2002a). Risk-aversion strategies in LEISA production systems do pose a problem for adapting forecast information. Low-income farmers are interested in a broader range of characteristics of precipitation, notably: total rainfall, patchiness of rainfall, intensity, starting date, distribution of rainfall, end of the rains and prospects for dry spells and their length (Blench, 1999; Ati et al., 2002). The use of this information then has to be adapted to local soils and topography.

It is exactly here, where scientific quantification/extensions and improvements of Stewart's response farming approach would bring highly needed solutions (Stewart, 1991; Gadgil et al., 2000). There are recent attempts to define conceptual strategies for demonstration projects of this kind, demanding strategic and tactical interactions between physical, agricultural, social and economic systems, with a long list of elements (Manton, 2001). Carefully organized, but less science driven pilot projects of that kind are highly needed, in which other experience referred to in this paper could be of much use as well (Gadgil, 2001; Stigter, 2002a, b).

4. Additional Considerations for Improving LEISA Farming

The literature on water related examples of combating climate variability and related phenomena of environmental hazards hold a series of lessons also applicable more generally. The above examples show that traditional management technologies and innovations of all kinds are and still become locally available. They belong to the best strategies to cope with climate variability. Dissemination through government and NGO efforts is, however, very necessary because successes are not widespread (Stigter, 2001). Upscaling of results from pilot projects has been reported to face particular barriers and needs wide additional attention (Turton and Bottrall, 1997).

Reports that population growth and agricultural intensification have been accompanied by improved rather than deteriorating soil and water resources (Tiffen et al., 1994) appear very conditional. Improvement of total land husbandry and wider livelihood as a whole are more important than controlling land degradation per se (Shaxson et al., 1997; Boyd and Slaymaker, 2000). The literature indicates that in places prone to frequent disaster or insecurity, simple solutions are bound to be more successful for services to decision making in the prevailing farming systems (Marsh, 2001). An analysis of soil and water conservation projects in Africa concluded that indigenous techniques should be a starting point to obtain success (Reij, 1993). More recent experience confirms this (Stigter and Ng'ang'a, 2001). Examples from Sri Lanka illustrate the role women's indigenous knowledge can play in conserving sustainability aspects (Ulluwishewa, 1994).

Science can play an appreciable role in increasing understanding and choosing between options for agrometeorological services (Figure 1, also e.g. MacLeod, 1997; Gadgil et al., 2000), but differences in concepts and interests between farmers and scientists should be explicitly recognized (e.g. Cartier van Dissel and de Graaff, 1998). Finally, it should be observed that experiments with traditional aspects of sustainable agriculture as exemplified in this paper provide important information, evidence and morale boosting for building agrometeorological services for decision making on risk management in agricultural systems. However, knowing their inherent limitations in actual agricultural practice, using contemporary science and policy support systems for guidance, is absolutely necessary. We want to make objectives and action plans (and their support systems) more realistic and to the point for creating (improved agrometeorological services for) sustainable livelihood systems (Santhakumar, 1995).

References

Abdalla, Ahmed el-Tayeb, Stigter, C. J., Mohamed, Habiballa A/Hafiz, Mohammed, Ahmed Eltayeb and Gough, M. C.: 2001, 'Effects of wall linings on moisture ingress into traditional grain storage pits',*Int. J. Biometeorol.* **45**, 75–80.

Abdalla, Ahmed el-Tayeb, Stigter, C. J., Gough, M. C., Mohamed, Habiballa A/Hafiz and Mohammed, Ahmed Eltayeb.: 2002a, 'Underground sorghum storage in cracking clay needs shallow pits, chaff linings and wide caps', *Trop. Sci.* **42**, 57–65.

Abdalla, Ahmed el-Tayeb, Kamal, Hamid Ali, Stigter, C. J., Adam, Ibrahim Adam, Mohamed, Habiballa A/Hafiz, Mohammed, Ahmed Eltayeb, and Gough, M. C.: 2002b, 'Impact of soil types on sorghum grain stored in underground pits in Central Sudan', *Agric. Eng. J.* **11**, 219–229.

Acosta Baladon, A. N.: 1995, *Agricultural Uses of Occult Precipitation*, Agrometeorological Applications Associates, Ornex, France, p. 146.

An, Yulin and Tuo, Debao.: 2001, 'Study on the land use sustainable and reasonable at ecotone in Inner-Mongolia', in ICAST (ed.), *Promoting Global Innovation of Agricultural Science & Technology and Sustainable Agriculture Development*, Session 3: Resources and Environment, Beijing, China, pp. 403–407.

Anonymous: 2001, 'Meteorology, folk wisdom, Junagadh: Traditional weather-forecasting on trial', *The Economist* 24th November 2001, pp. 82–83.

Arnold, M. and Dewees, P.: 1998, 'Rethinking approaches to tree management by farmers', *Nat. Resource perspect.* **26**, ODA, London, p. 9.

Ati, O. F., Stigter, C. J., and Oladipo, E. O.: 2002, 'A comparison of methods to determine the onset of the growing season in Northern Nigeria', *Int. J. Climatol.* **22**, 731–742.

Bakheit, Nageeb Ibrahim, Stigter, K., and Abdalla, Ahmed el-Tayeb.: 2001, 'Underground storage of sorghum as a banking alternative', *LEISA Magazine* **17**(1), p.13.

Baldy, Ch. M. and Stigter, C. J.: 1997, *Agrometeorology of Multiple Cropping in Warm Climates*, Translated from the French with an Epilogue to the English edn., INRA, Paris, France; Oxford & IBH Publishing Co., New Delhi, India; Science Publishing Inc., Enfield, U.S.A., p. 237.

Berg, T., Dava, F., and Muchanga, J.: 2001, 'Post-disaster rehabilitation and seed restoration in flood affected areas of Xai-Xai District, Mozambique', *SD dimensions*, p. 6, Retrived from http://www.fao.org/sd

Blench, R.: 1999, 'Seasonal climate forecasting: Who can use it and how should it be disseminated', *Nat. Resource perspect.* **47**, ODA, London, p. 4.

Blench, R. and Marriage, Z.: 1998, 'Climatic uncertainty and natural resource policy: What should the role of government be?' *Nat. Resource perspect.* **31**, ODA, London, p. 8.

Boffa, J.-M.: 1999, 'Agroforestry parklands in sub-Saharan Africa', *FAO Conservation Guide* **34**, FAO, Rome, p. 230.

Boyd, C. and Slaymaker, T.: 2000, 'Re-examining the "more people less erosion" hypothesis: Special case or wider trend?', *Nat. Resource perspect.* **63**, ODA, London, p. 6.

Brokensha, D., Warren, D. M., and Werner, O.: 1980, *Indigenous Knowledge Systems and Development*, University Press of America, Lanham, p. 460.

Bunting, A. H.: 1975, 'Time, phenology and the yields of crops', *Weather* **30**, 312–325.

Byron, N. and Shepherd, G.: 1998, 'Indonesia and the 1997–98 El Nino: Fire problems and long-term solutions', *Nat. Resource perspect.* **28**, ODA, London, p. 8.

Cartier van Dissel, S. and de Graaff, J.: 1998, 'Differences between farmers and scientists in the perception of soil erosion: A South African case study', *Indigenous Knowledge and Dev. Monitor* **6**(3), p 4. Also on http://www.nuffic.ciran

Clemens, M. and Nashrullah, L. H.: 1999, 'Wild food plants in an indigenous food and agricultural system: A case study from west Java', in Adimihardja, K. and Clemens, M. (eds.), *Indigenous Knowledge Systems and Development*, UPT.INRIK – UNPAD, Bandung, Indonesia, pp. 44–54.

Das, H. P.: 2001, *Potential of Water Harvesting in India by Traditional Methods in Semi-Arid and Arid Zones of India,* contribution submitted for this paper to WMO/CAgM.

Diarra, B.: 2001, 'Agrometeorologie au service d'un developpement humain durable au Mali', in *Contributions from Members on Operational Applications in Agrometeorology and from Discussants on the Papers Presented at the International Workshop: "Agrometeorology in the 21st Century, Needs and Perspectives"*, CAgM Report No. 77b, WMO/TD No. 1029, WMO, Geneva, pp 41–42.

Gadgil, S., Sestagiri Rao, P. R., Narahari Rao, N., and Savithri, K.: 2000, 'Farming strategies for a variable climate', in: Sivakumar, M. V. K. (ed.), *Climate Prediction and Agriculture*, Int. START Secretariat, pp. 215–248.

Houghton, J.: 1997, *Global Warming: The Complete Briefing*, (2nd edn.), Cambridge University Press, p. xv, 251.

ILEIA: 1995, 'Research and reality', *ILEIA Newsletter* **11**(2), p. 36.

Karing, P. H., Stigter, C. J., Chen, Wanlong, and Wilken, G. C.: 1992, 'Application of microclimate management and manipulation techniques in low external input agriculture', in Stigter C. J. (ed.), *CAgM Report No. 43*, WMO/TD-No. 499, World Meteorological Organization, Geneva, p. 192.

Katz, A. R.: 2002, 'Sahara is contracting as climate issues grow', *Wall Street J. Eur.* 16 October 2002, p. A12.

LEISA: 2000, 'Grassroots innovation', *ILEIA Newsletter* **16**(2), p. 40.

LEISA: 2001, 'Coping with disaster', *LEISA Magazine* **17**(1), p. 36.

Luo, Shiming: 2001, 'An ecological approach to sustainable agricultural development', in ICAST (ed.), *Promoting Global Innovation of Agricultural Science & Technology and Sustainable Agriculture Development*, Session 2: Sustainable Agriculture, Beijing, China, pp. 56–59.

Manton, M. J.: 2001, 'Climate prediction to enhance agricultural production in developing countries', in ICAST (ed.), *Promoting Global Innovation of Agricultural Science & Technology and*

Sustainable Agriculture Development, Session 3: Resources and Environment, Beijing, China, pp. 307–309.

MacLeod, K.: 1997, 'Seeking sustainability in rural Egypt: Linking scientific and indigenous knowledge', *IDRC Reports*, Retrived from http://www.idrc.ca/books/reports

Marsh, N.: 2001, 'It is time to celebrate the spirit of the African farmer', *LEISA Magazine* **17**(1), 14.

MOST/CIRAN: 'The bethma practice: Promoting the temporary redistribution of lands during drought periods', SRI LANKA, BP.21, *Best Practices on Indigenous Knowledge Database*, Retrived from http://www.nuffic.ciran

MOST/CIRAN: 'Improving tassa planting pits: Using indigenous soil and water conservation techniques to rehabilitate degraded plateaus in the Tahoua region of Niger', NIGER, BP.10, *Best Practices on Indigenous Knowledge Database*, Retrived from http://www.nuffic.ciran

MOST/CIRAN: 'Ecological restoration of degraded watershed on the upper reaches of the Minjiang River: Integration of Qiang ethno-botanical knowledge and practices into a reforestation project', China, BP.15, *Best Practices on Indigenous Knowledge Database*, Retrived from http://www.nuffic.ciran

Mungai, D. N. and Stigter, C. J.: 1993, 'The use of weather and climate information in planning and management of food security and production in Africa under conditions of increasing climate variability', Chapter 7.1 in *Proceedings of the First International Conference of the African Meteorological Society* on *"Recent Climate Anomalies and Prediction in Africa"*, Nairobi, Kenya, pp. 596–600.

Mungai, D. N., Stigter, C. J., Coulson, C. L., Ng'ang'a, J. K., Netondo, G. W. S., and Umaya, G. O.: 2001, 'Understanding yields in alley cropping maize (*Zea Mays L.*) and *Cassia siamea Lam*. under semi-arid conditions in Machakos, Eastern Kenya', *J. Environ. Sci.* **13**, 291–298.

Murthy, V. R. K.: 2002, 'A cry for help after serious hail damage in India', *Needs for Agrometeorological Solutions to Farming Problems*, Retrived from INSAM website http://www.agrometeorology.org.

Nasr, N., Chahbani, B., and Ben Ayed, A.: 2000, 'Innovation by Tunisian women in dryland farming', *ILEIA Newsletter* **16**(2), p.20.

Norman, D. W.: 2001, 'Survival and sustainability in low-income countries: Incorporating farming households in the struggle', in ICAST (ed.), *Promoting Global Innovation of Agricultural Science & Technology and Sustainable Agriculture Development*, Session 2: Sustainable Agriculture, Beijing, China, pp. 112–124.

Norse, D. and Tschirley, J. B.: 2000, 'Links between science and policy making', *Agric. Ecosystem Environ.* **82**, 15–26.

Olufayo, A. A., Stigter, C. J., and Baldy, C.: 1998, 'On needs and deeds in agrometeorology in tropical Africa', *Agric. Forest Meteorol.* **92**, 227–240.

Ong, C. K., Kinama, J., Chiti, R., Gichuki, F., Stigter, C. J., and Ng'ang'a, J. K.: 1996, 'Agroforestry for soil and water conservation in drylands', in: Mugah, J. O. (ed.), *People and Institutional Participation in Agroforestry for Sustainable Development*, First Kenya Agroforestry Conference, NASC and ICRAF, Nairobi, pp. 297–308; Also appeared as *E. Afr. Agric. Forest J.* **62**, 151–162.

Onyewotu, L. O. Z, Stigter, C. J., Oladipo, E. O., and Owonubi, J. J.: 1998, 'Yields of millet between shelterbelts in semi-arid northern Nigeria, with a traditional and a scientific method of determining sowing date, and at two levels of organic manuring', in Van Duivenbooden, N. and Neeteson, J. J. (eds.), *Using Scientific and Indigenous Knowledge at Different Scale Levels to Develop Sustainable Agriculture in the Sudano-Sahelian Zone of West Africa, Neth. J. Agric. Sci.* **46**, 53–64.

Onyewotu, L. O. Z, Stigter, C. J., Abdullahi, A. M., Ariyo, J. A., Oladipo, E. O., and Owonubi, J. J.: 2003, 'Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: A case study of Yambawa rehabilitation scheme', *Arid Land Res. Manage.* **17**, 85–101.

Orev, Y.: 1986,'A practical handbook on desert range improvement techniques', *Interagency Group on Agricultural Biometeorology*, FAO/UNEP/UNESCO/WMO, Geneva, 165 pp.

Othieno, C. O., Stigter, C. J., and Mwampaja, A. R.: 1985, 'On the use of Stigter's ratio in expressing thermal efficiency of grass mulches', *Expl. Agric.* **21**, 169–174.

Paltridge, I. J. and Ma'shum, M. (eds.): 2002, *Will it Rain? The Effect of the Southern Oscillation and El Nino in Indonesia*, Department Primary Industries, Queensland, Australia, p. 50.

Reij, C.: 1993, 'Improving indigenous soil and water conservation techniques: Does it work?', Indigenous Knowledge Dev. Monit. **1**(1), 4 pp ; Also on http://www.nuffic.ciran

Reijntjes, C., Haverkort, B., and Waters-Bayer, A.: 1992, *Farming for the Future: An Introduction to Low-External-Input and Sustainable Agriculture*, Macmillan Education Ltd./ILEIA, London/Leusden, p. 250.

Rivero Vega, R. E.: 2002, 'Adaptation measures in areas prone to hail damage', in *Accounts of Operational Agrometeorology*, Retrived from INSAM Web site http://www.agrometeorology.org

SAAS: 1977, *What can we do for Crops Damaged by Hail?*, Shandong Academy of Agricultural Sciences, Laboratory of Agrometeorology, Agricultural Press (in Chinese).

Salinger, M. J., 2004. 'Climate variability and change; Past, present and future: An overview', *Climatic Change*, submitted for this volume.

Salinger, M. J., Desjardins, R. L., Jones, M. B., Sivakumar, M. V. K., Strommen, N. D., Veeresamy, S., and Wu, Lianhai: 1997, 'Climate variability, agriculture and forestry: an update', *WMO Technical Note 199*, WMO, Geneva, p. 124.

Salinger, M. J., Stigter, C. J., and Das, H. P.: 2000, 'Agrometeorological adaptation strategies to increasing climate variabilty and climate change', in: Sivakumar, M. V. K., Stigter, C. J. and Rijks, D. A. (eds.), *Agrometeorology in the 21st Century: Needs and Perspectives*, *Agric. Forest Meteorol.* **103**, 167–184.

Santhakumar, V.: 1995, 'Research on sustainable agriculture compared'. *ILEIA Newsletter* **11**(2), 24–25.

Shaxson, F., Tiffen, M., Wood, A., and Turton, C.: 1997, 'Better land husbandry: Re-thinking approaches to land improvement and the conservation of water and soil', *Nat. Resource perspect.* **19**, ODA, London, p. 8.

Shumba, O.: 2001, 'Farmers' responses to reduce the risks of drought', *LEISA Magazine* **17**, 8–9.

Slikkerveer, L. J.: 1999, 'Traditional ecological knowledge (TEK): Practical implications from the African experience', in: Adimihardja, K. and Clemens, M. (eds.), *Indigenous Knowledge Systems and Development*, UPT.INRIK – UNPAD, Bandung, Indonesia, pp. 24–25.

Smith, L. P. (ed.): 1972, *The Application of Micrometeorology to Agricultural Problems*, WMO Technical Note No. 119, WMO-No. 298, p. 74.

Stewart, J. I.: 1988, *Response Farming in Rainfed Agriculture*, WHARF Foundation Press, Davis, p. 115.

Stewart, J. I.: 1991, 'Principles and performance of response farming', in Muchow, R. C. and Bellamy, J. A. (eds.), *Climate Risk in Crop Production: Models and Management for the Semi-Arid Tropics and Sub-Tropics*, CAB International, Wallingford, pp. 361–382.

Stigter, C. J.: 1988, *Microclimate Management and Manipulation in Traditional Farming*, *CAgM Report No. 25, WMO/TD-No. 228*, World Meteorological Organization, Geneva, p. 20, VI Appendices.

Stigter, C. J.: 1994, 'Management and manipulation of microclimate', in Griffiths, J. F. (ed.), *Handbook of Agricultural Meteorology*, Oxford University Press, Chapter 27, pp. 273–284.

Stigter, K.: 1995, 'Transfer of indigenous knowledge and protection of the agricultural environment in Eastern Africa', in Warren, D. Michael, Slikkerveer, L. Jan and Brokensha, David (eds.), *The Cultural Dimension of Development: Indigenous Knowledge Systems*, Intermediate Technology Publications (IT studies in indigenous knowledge and development), London, pp. 419–425.

Stigter, C. J.: 1999, 'The future of agrometeorology: Perspectives in science and services', *WMO-Bull.* **48**, 353–359.

Stigter, C. J.: 2001, 'Operational agrometeorology in Africa and Asia: Lessons for sustainable agriculture', in ICAST (ed.), *Promoting Global Innovation of Agricultural Science & Technology and Sustainable Agriculture Development*, Session 2: Sustainable Agriculture, Beijing, China, pp. 276–280.

Stigter, C. J.: 2002a, 'Opportunities to improve the use of seasonal climate forecasts' and 'Climate related extreme events: A review of adaptation options', in ADPC (ed.), *Asian Climate Traing Course*. ACT, Asian Disaster Preparedness Center, Bangkok, Thailand, CD-ROM.

Stigter, C. J.: 2002b, 'Introduction to Indonesian condition: Applying climate information for decision making in agricultural production; adaptation options in agricultural production to climate related extreme events', in UNSRAT (ed.), *Climate and Agriculture Production,* Lecture Notes, Seminar in Agrometeorology, Faculty of Agriculture, Sam Ratulangi University, Manado, Indonesia.

Stigter, C. J. and Baldy, Ch.M.: 1993, 'Manipulation of the microclimate by intercropping: Making the best of services rendered', in Sinoquet, H. and Cruz, P. (eds.), *Ecophysiology of Tropical Intercropping*, INRA, Paris/Guadeloupe (French Antilles), 29–44.

Stigter, C. J. and Ng'ang'a, J. K.: 2001, 'Traditional techniques of microclimate improvement African network (TTMI/AN) project for research training', *Successful Research Training Partnership Case Study for GFAR-2000*, Global Forum on Agricultural Research, Rome, CD-ROM.

Stigter, C. J., Sivakumar, M. V. K., and Rijks, D. A.: 2000, 'Agrometeorology in the 21st Century: Workshop Summary and Recommendations on Needs and Perspectives', in: Sivakumar, M. V. K., Stigter, C. J. and Rijks, D. A. (eds.), *Agrometeorology in the 21st Century - Needs and Perspectives*, *Agric. Forest Meteorol.* **103**, 209–227.

Stigter, C. J., Mohammed, Ahmed El-Tayeb, Al-amin, Nawal K. Nasr, Onyewotu, L. O. Z., Oteng'i, S. B. B., and Kainkwa, R. M. R.: 2001, 'Some African case studies of local solutions to problems caused by wind in smallholder agroforestry', *Proceedings of the 3rd European & African Conference on Wind Engineering*, July, Eindhoven, The Netherlands, pp. 419–426.

Stigter, C. J., Mohammed, Ahmed El-Tayeb, Al-amin, Nawal K. Nasr, Onyewotu, L.O.Z., Oteng'i, S. B. B. and Kainkwa, R. M. R.: 2002, 'Agroforestry solutions to some African wind problems', *J. Wind Eng. Ind. Aerodyn* **90**, 1101–1114.

Tchawa, Paul: 2000, 'Chains of innovations by farmers in Cameroon', *ILEIA Newsletter* **16**(2), 14–15.

Tiffen, M., Mortimore, M., and Gichuki, F.: 1994, *More People, Less Erosion: Environmental Recovering in Kenya*, Wiley, Chichester, p. 311.

Traore, K., Diarra, B., and Konare, K.: 1992, 'Elaboration et mise en oevre de projets pilotes en agrometorologie (Development and use of pilot projects in agrometeorology)', in *La radio rurale et la diffusion des informations agrometeorologiques (Rural Radio and Broadcasting of Agrometeorological Information)*, WMO/CTA, Geneva/Wageningen, p. 340.

Turton, C. and Bottrall, A.: 1997, 'Water resource development in the drought-prone uplands', *Nat. Resource perspect.* **18**, ODA, London, p. 8.

Ulluwishewa, R.: 1994, 'Women's indigenous knowledge of water management in Sri Lanka', *Indigenous Knowledge Dev. Monit.* **2**(3), p. 4. Also on http://www.nuffic.ciran

Van Viet, Nguyen: 2001, 'The influence of climatic variation on the production of winter-spring rice in the north delta of Viet Nam and the means to cope with it', in *Contributions from Members on Operational Applications in Agrometeorology and from Discussants on the Papers Presented at the International Workshop: "Agrometeorology in the 21st Century – Needs and Perspectives"*, CAgM Report No. 77b, WMO/TD No. 1029, WMO, Geneva, pp 103–108.

Warren, D. M., Slikkerveer, L. J., and Brokensha, D. (eds.): 1995, *The Cultural Dimension of Development: Indigenous Knowledge Systems*, Intermediate Technology Publications (IT studies in indigenous knowledge and development), London, p 582.

Wilken, G. C.: 1972, 'Microclimate management by traditional farmers', *Geogr. Rev.* **62**, 544–560.

Wilken, G. C.: 1987, *Good Farmers: Traditional Agricultural Resource Management in Mexico and Central America*, University of California Press, Berkley, p. 302.

WMO: 1993, 'Applications of meteorology to forestry', Chapter 8 (Supplement No. 3) in *Guide to Agricultural Meteorological Practices*, 2nd. edn., WMO:No. 134, Chapter 8, p. 30.

WMO: 2002, *Current Advances in Seasonal Forecasts and Climate Prediction and the Products and Services Relevant to Agriculture*, CAgM-XIII/Doc. 9.5, item 9.5.7 on the CLIMAG South Asia project.

Zheng, Dawei and Tuo, Debao: 1999, 'The way of sustainable development in the interlock belt of cultivation and grazing according to the practice of ecological harness in Houshian area of dryland farming', in *Proceedings of the Workshop on Economic and Environmental Sustainable Development in Middle and Western Region of China in the 21st Century*, Inner Mongolia People's Publishing House, Hohhot, p. 7.

Zheng, Dawei (ed.), with contributions from seven co-authors: 2001, 'Agrometeorology in the 21st century: The needs and prospects in China', in *Contributions from Members on Operational Applications in Agrometeorology and from Discussants on the Papers Presented at the International Workshop: "Agrometeorology in the 21st Century - Needs and Perspectives"*, CAgM Report No. 77b, WMO/TD No. 1029, WMO, Geneva, pp 13–29.

Zimmerman, R.: 2001, 'Agrometeorological aspects of agriculture in the eastern zone of El Salvador', in *Contributions from Members on Operational Applications in Agrometeorology and from Discussants on the Papers Presented at the International Workshop: "Agrometeorology in the 21st Century – Needs and Perspectives"*, CAgM Report No. 77b, WMO/TD No. 1029, WMO, Geneva, p 121.

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