Net Journal of Agricultural Science
Vol. 4(4), pp. 67-77, December 2016
ISSN: 2315-9766
Review

Improving agricultural decision making using weather and climate information for farmers, south-western Free State, South Africa

Gugulethu NC Zuma-Netshiukhwi[1, 3]*, Kees CJ Stigter[2] and Sue Walker[3]

[1]Agricultural Research Council-Institute for Soil, Climate and Water, Glen Agricultural College, Glen, Republic of South Africa, 9360.
[2]Agromet Vision (Netherlands, Indonesia, Africa) Groenestraat 13, Bruchem 5314 AJ, The Netherlands.
[3]Department of Soil, Crop and Climate Sciences, University of the Free State, PO Box 339, Bloemfontein 9301, South Africa.

Accepted 24 November, 2016

ABSTRACT

Science based knowledge and services related to weather forecasts, climate predictions and establishment of other knowledge based climate services make farmers more climate resilient. Various farmers in the south-western Free State and other parts of South Africa, among many others, are highly vulnerable to the impact of an increasingly variable climate. Furthermore, weather and climate influence both animal production and agronomic production. Occurrences of extreme climate events, such as floods, droughts, severe storms threaten the agricultural sector's food security and economic growth. Farmers in the south-western Free State lack access to informed tailor-made weather and climate knowledge and other simple climate services. Such services are critical to guide farmers to make well-informed decisions about matters such as when to prepare the land, when to plant, what to plant, pest and insect management, fertilizer applications, grazing camp management, installation of correct shelters, breed tolerance. This study provided training on the application of weather forecasts and climate predictions and other services made available assists farmers to improve their resilience to climate change and its consequences. Increasing platforms of knowledge exchange and sharing and of cooperation in applications between key stakeholders would have an appreciable positive influence on yields and food security. Thus, farmers who participated and adopted weather forecasts, climate predictions and other science based information for decision making had better yield comparing to those who were not part of the study. In this study, efforts were made to engage with farmers, knowledge producers (weather and other environmental services agencies, universities, research institutes) and extension to apply new knowledge with farmers and to create better understanding of the application of agrometeorological information for improved decision making.

Keywords: Agriculture, decision making, application, advisories.

*Corresponding author. E-mail: ZumaNetshiukhwiG@arc.agric.za. Tel: +27-12-310-2500.

INTRODUCTION

The application of weather and climate knowledge (Stigter, 2010; Stigter, 2016; Stigter and Winarto, 2015a; Stigter and Winarto, 2015b) plays a crucial role in all aspects of agriculture, irrespective of whether it is crop production, animal husbandry, agroforestry, pasture use, food processing or storage. Informed decisions for tactical and strategic production approaches are possible with operationalized meteorological/climatological contents of short and long-term applications (Stigter, 2010). Weather forecasts and climate predictions must be made available into agricultural terms for economic benefits and reduction of risks (Calanca, 2014; Murthy, 2008; Murthy and Stigter, 2004; Zuma-Netshiukhwi, 2012). Agricultural planning is critical to mitigate the impacts of increasing climate variability and more (and often more severe) weather and climate extreme events (Stigter and Ofori, 2014a; Stigter and Ofori, 2014b).

Failures in agricultural production are often a result of lack of tailor-made agrometeorological products and poor channels of knowledge transfer (Zuma-Netshiukhwi et al., 2013). The dissemination and usage of agrometeorological knowledge is the central part of the innovative case study described in this paper, by simply providing and communicating weather and climate knowledge and other climate services to farmers; with sufficient lead-time to fine-tune critical agricultural decisions and presented according to production systems and outcomes at a given scale for relevant decisions and choices (Baethgen et al., 2009). Such knowledge leads to adjustment of agricultural activities implementation, for example land preparation, planting date, fertilizer application, weed control, pest and disease management and harvesting.

Farmers are rather more interested in knowing the likelihood of crop yield distributions and, importantly, the economic returns of each and every agricultural enterprise established on farm, compared to receiving just a seasonal rainfall forecast (Calanca, 2014; Stigter et al., 2016a; Stigter et al., 2016b; Zuma-Netshiukhwi, 2012). There exists also a gap between national and regional climate prediction and weather forecast centers and the needs of farmers, agricultural extension agents and other agricultural decision-makers (Calanca, 2014; Zuma-Netshiukhwi, 2012). Climate services cannot be given with the assumption that farmers have access to agricultural tools and technologies such as machinery: tractor, ploughs, discs, rippers; suitable crop types and crop varieties; fertilizer requirements and their applications, integrated pest management; supplementary irrigation and access to short-time scale weather forecasts and trustable seasonal climate forecasts. That is why such climate services must be farmer and farming system specific (Stigter, 2010).

Recently, Stigter and Winarto (2016) exemplified how tropical lowland rice production in Indonesia suffers from climate change and how short-term seasonal rainfall prediction and other services improve its resilience. Two problems haunt seasonal climate predictions for farmers. These are the skill of predictions and the terminology chosen for monthly updated seasonal rainfall predictions. These “scenarios” are part of climate change adaptation attempts (Stigter et al., 2016a; Stigter et al., 2016b).

Alternative scenarios based on climate conditions can be developed using climate data retrieved from local automatic weather stations, models simulating crop yields and biophysical response variables (Zuma-Netshiukhwi, 2012). A number of decision support models have been tried and tested to simulate processes in agricultural production systems that determine crop performance, crop growth, crop response, phenological growth, resource use, management scenarios, environmental conditions and resource use. However, to get such results tried by small farmers in developing countries demands extension structures that do presently not exist (Nanja, 2011; Nanja and Walker, 2011).

Application of weather forecasting, climate prediction and other climate services in agricultural production has met with many limitations to end-user in developing countries, and most particularly related to resource poor farmers (Archer, 2003; Stigter and Winarto, 2016; Ziervogel and Downing, 2004). There has been rising interest in working with farmers in reaching out with new technologies and science-based knowledge to many farmers (Aw-Hassan, 2008; Erbaugh, 2007; Stigter, 2005; Winarto and Stigter, 2016). A large problem is the absence of a well-trained and well-established extension on climate change related issue (Stigter, 2011; Stigter and Winarto, 2016). This comes together with a continuous need for abilities to translate technical detail into a digestible format. There is a gap between producers and suppliers from the national, provincial, regional and local networks and the users in need of weather forecasts, climate predictions and other climate services for on-farm decision making (Stigter, 2011; Stigter et al., 2016b). Another identified gap is how intermediaries ensure the encouragement for adaptation of agrometeorological knowledge/advisories/services for decision-making (Stigter et al., 2016b; Zuma-Netshiukhwi, 2012). Identification of agrometeorological knowledge, advisories, services producers and suppliers and stakeholder networks, intermediaries should be catalysts to strengthen the channels of efficient agrometeorological knowledge/advisories/services dissemination (Stigter, 2010, 2016). Thereafter, identification of the constraints for effective adoption can be included to effectively encourage the adaptation of science-based knowledge for use in improved agricultural production (Stigter, 2011; Valente, 1995). Agrometeorological knowledge/advisories/services use in on-farm decision making on a routine basis will improve productivity and minimize risks (Stigter, 2010; Stigter et al., 2016b).

Extreme meteorological events that are increasing in number and severity due to climate change are already serious enough (IPCC, 2007; Stigter, 2015; Stigter and Ofori, 2014a). But they also have the potential to instigate and/or alter pest and disease infestations, which result in more crop damage and failure (Thornton and Cramer, 2012). Therefore, early warnings and response farming are crucial for preparedness so that interventions can be implemented to reduce possible damages and risks (Stigter and Ofori, 2014b). The variability of weather within the season has significant impact on timing and planning of agricultural practices such as times of ploughing, planting, weeding, harvesting, storage and of application of fertilizers and pesticides (Berggren, 1978; Thornton, 2012). The timely provision of agrometeorological information, advisories, services to farmers and decision makers in the agricultural sector will assist strategic planning such as crop suitability selection and management practices for sustainable agricultural production (Stigter, 2010; Stigter, 2016; Ziervogel and Downing, 2004). Already, a World Development Report dated 1998/99 (World Bank, 1998) emphasized the importance of knowledge as factor of production. Knowledge plays an imperative role in human development and behavioral change. The report distinguishes between two sorts of knowledge: knowledge about technology, called technical knowledge or simply know-how, and knowledge about attributes, that is, knowledge about products, processes, and institutions (World Bank, 1998).

Availability and accessibility of agrometeorological services/knowledge/advisories differ from country to country and for different types of farmers. For example resource poor farmers are disadvantaged since such knowledge is not incorporated into their daily decision making (O'Brien et al., 2000; Stigter, 2010). Agricultural knowledge/advisories/services dissemination from developers to suppliers to farmers (Stigter, 2010) could reach a fair number of respondents in Malawi, Tanzania and Free State Province in South Africa (Mukhala, 2000) and in Lesotho (Ziervogel and Downing, 2004). Within the dissemination process several blockages and gaps can be identified such as lack of access to internet, difficulties in understanding technical terminology and knowledge/advisories/services not reaching the end-users in time (Ziervogel and Downing, 2004). Several constraints also occur in modelling the weather and climate systems as complexities exist within these systems, such that weather forecasts are not point specific, obtained at unsuitable temporal resolutions, with only few selected climate parameters predicted, and with the forecasts having little skill (Ziervogel and Downing, 2004). However, some agrometeorological advisories may still carry substantial support for practical decision-making, which can be disseminated through institutionalized study groups or any other well-established knowledge dissemination channels and networks that allow the provision of feedback from end-users (Stigter et al., 2016a; Stigter et al., 2016b).

Meaningful and valuable advisories and services on weather forecasts and climate predictions and other knowledge inputs for a wider agricultural community need to be well thought through, and different types of network channels should be established. Science-based knowledge should be made understandable through all channels of dissemination to all different end-users (Ziervogel and Downing, 2004). The nature of channels and networks through which the knowledge/advisories/services should flow needs to be identified and reviewed in order to improve their transfer and applications (Day et al., 1995; Stigter, 2016) explained that dissemination should be by means of two-way communication channels. This was confirmed by the Science Field Shops developed as a participatory extension method in Indonesia (Stigter et al., 2016a). These communication channels must advance the sharing of meaning and support abilities for successful application of knowledge/advisories/services (Mukhala, 2000). According to Ziervogel and Downing (2004) in the case study they conducted, it was imperative to determine effective methods and channels of dissemination by achieving key points. Examples were (i) evaluation of the user's perceptions on weather forecasts and climate predictions, (ii) identification of suitable dissemination methods, (iii) establishment of agricultural enterprises suitable per location, (iv) investigation of the interaction of users so as to uncover other existing networks, and (v) contextualizing the importance of weather forecasts and climate predictions within their wider decision making environment. The same can be said for other climate services in agriculture.

In our study area (South-western Free State, the types of projects that are catered for include food security projects, equity schemes, production for markets and agriculture in communal land. Therefore, this research became a necessity to provide weather, climate and other science based information toward supporting farmers for developing informed agricultural decisions. Farmers in the study area depended only on traditional ways of farmers which excluded weather forecast and climate predictions for agricultural decision making. The success of farmers is dependent on the provision of science based knowledge, machinery to work the land, input supplies, research, extension, household finance, markets and infrastructure (Lyne and Darroch, 2003). These support services may be provided by state ministries and private sectors. Amongst other, provision of agrometeorological knowledge, agro-advisories and services could play a crucial function towards sustainability of crop productivity, animal husbandry and agroforestry (Stigter, 2010). Numerous studies locally and internationally have shown that agricultural led growth has high potential to drive economic reform in developing countries through improved employment rates, on-farm and off-farm income generation (IPA, 2012). The overall goal of the study was to explore examples of agricultural on-farm decision-making changed due to the availability of science-based climate/weather information/advisories in comparison with the traditionally used information. Ultimately, the farmers were asked to make the comparison where applicable. This particularly contributes to increasing the useful operational applicability of weather science, climate science and various fields of agricultural sciences. This must be seen as a contribution to science itself.

The eagerness to adopt agricultural technologies and science-based knowledge depends upon the farmer's expectations for improved increments of outputs and reduction of constraints to crop production. Good profit from agricultural productivity has great impact on household food security.

METHODOLOGY

This research consisted of three major parts, which were: (a) interaction with the community; (b) understanding of the farming systems concerned and (c) development of advisories using existing weather/climate information products. The Farming Systems approach to Development was complemented by the use of participatory tools (e.g. questionnaires, discussion in groups and with key informants, buzz questions) and techniques (e.g. a Participatory Rural Appraisal Approach). An action learning cycle will be used, leading to the improved dissemination and application of weather/climate information and products/advisories in agrometeorological decision making for improved livelihoods. The methodology used for this study incorporated qualitative and quantitative methodologies. This paper serves to provide the review of the work conducted at the selected study area.

Long-term climate data was from weather stations available across the study was analyzed and used to identify seasonal distributions, onset/cessation, and probabilities of amounts of rainfall. Crop simulation models were utilized for the development of different scenarios based on weather forecast and climate prediction. Thus should assist farmers to identify alternative crops that could suitable for their environmental conditions.

DISCUSSION

Situation in our case study area

Collectivity in farming

There is a wide diversity of farming activities practiced across the selected area, which range from growing grains, vegetables, fruits, to keeping small and large stock animals. In the south-western Free State collective farming was organized by researchers in partnership with extension agents through study groups that were organized for a given area. Collective farming and its concept of agricultural cooperative was adopted whereby farmers pull together their resources in certain areas of agricultural related activities. In the study area, two kinds of agricultural cooperatives were distinguished: (i) agricultural service cooperatives, whereby services were provided to individual farmers according to their specific needs; (ii) agricultural production cooperatives where production resources such as land and machinery were jointly utilized for farming by all members. It is worth noting that many households in the south-western Free State depend on farming as well as off-farm activities to generate income. Households who continue to practice farming have the responsibility of taking care of the fields, animals and agroforestry.

Farmers in the study area differ in land scale, skill, capacity and resources. Therefore, it became imperative to adopt the typology of agricultural cooperatives and render services as suitable to farmers in a practical manner. There is indeed a diversity among farmers in terms of resources: (a) a group that acquired all farm resources, (b) a group that depends on other farmers to lease implements, and (c) another group that owns the land but has poor resources. This illustrates south-western Free State as a land of contrasts and lacking in equality. During study group facilitation, farmers were encouraged to work collectively and interactively. For example, farmers traded amongst each other crop residues with animal producers as feed in exchange for land cultivation services, while some farmers traded a prescribed amount of tons of maize for slaughtering farm grown animals. Other farmers exchanged laborers during transplanting, planting, weeding and harvesting. The culture of sharing and voluntarism among the farming community was encouraged in cases of farmers who are not able to perform certain activities. Mentorship by well-established farmers to poor resource farmers was promoted as part of skill transfer amongst farmers of same agricultural interest. Agriculture related stakeholders and local institutions played a remarkable role in ensuring collectivism in farming and providing external assistance toward improved decision making and sharing of resources.

Farmer differentiation

A survey conducted in the study area which incorporated the two district municipalities of Motheo and Lejweleputswa, explored among others the farm systems, the application of weather forecasts and climate predictions and the accessibility and availability of other agrometeorological knowledge, advisories, and services. During the survey, farmers from different levels were given a set of questionnaires designed to assess three major production factors: (i) the farming systems, (ii) the availability of weather forecasts and climate predictions to the farmers and (iii) the use of such science-based products by the farmers.

Differences in annual rainfall defined agricultural suitability and practices. In the study area, the annual rainfall differs significantly and ranges between 200 and 700 mm. The annual rainfall on the western part of the catchment ranges from 200 to 300 mm, which is an indication of severely dry conditions; the middle part of the study area receives from 500-600 mm of annual rainfall; and the eastern part of the catchment is a wetter area compared to the other parts, with 600 to 700 mm of annual rainfall. The questionnaire analysis indicated that close to 53% were commercial farmers and just over 47% were resource poor farmers. As earlier indicated the actively grown agricultural commodities were identified as grain, vegetable and fruit productions under rain-fed and irrigated conditions, while animal husbandry and agroforestry are also substantial agricultural enterprises within the study area. The survey confirmed that farming systems, agricultural practices, farming interests, farming needs, agricultural skills and experience differed from farmer to farmer. The questionnaire analysis indicated that farmers were numerically involved in the following agricultural enterprises: crops 4%, livestock 25%, mixed farming (crops and livestock) 35% and agroforestry (crops and trees) 36%.The participants were indeed fulltime and part time farmers earning income with agricultural activities and off-farm activities. The mean age of farmers was 47 years.

The preferred methods of knowledge obtainment as chosen by the famers was rated as follows: close to 4% preferred radio, 3% preferred television, 27% preferred active internet, just over 28% preferred meetings or study groups, almost 5% preferred e-mail (passive internet), 11% remained unspecified and 22% indicated none. The methods of communication were thoroughly discussed to explain the advantages and disadvantages for each of them as suggested and preferred by farmers. The most popular communication method was the monthly meetings, since farmers are able to react and ask questions to intermediaries[48], followed by radio broadcasting, local freely available newspapers and lastly via the extension officers in places where extension support was recognized.

Challenges faced by farmers

Like in any other farming community worldwide, farmers are faced by climate variability, these days with increasing climate variability (Stigter and Ofori, 2014a; Stigter and Ofori, 2014b), difficult environmental conditions (soils, climate, pest and diseases) and other disadvantages to sustainable agricultural productivity. Limitations in farming could be minimized by well-informed decisions on the basic needs of a particular unique agricultural commodity. Therefore, needs analysis exercises established that farmers were faced by a range of agrometeorology related problems such as: water scarcity, weather extremes, outbreak of diseases and pests, manifestation of weeds, prolonged wet and dry spells within the growing season to list the major challenges. This was a clear indication that amongst other challenges farmers had no access to agrometeorological knowledge, advisories, and services since encountered problems were weather/climate related. Therefore, extension of new technologies and most importantly agrometeorological knowledge, advisories and services are needed to significantly train farmers and that way increase and improve agricultural production (Winarto and Stigter, 2016).

Such technologies are based on the choices and selection of agricultural enterprises, planting of crops/varieties, planting dates and densities, applications of fertilizers and pesticides, weeding times and frequencies, and irrigation scheduling. Therefore, also provision of daily to seasonal scenarios for decision making, based on weather forecasts, climate predictions and services for the other technologies mentioned, was crucial to influence the implementation of agricultural activities. Farmers need to be supported with such advisories prior to the planting seasons, within seasons and off-season for better preparations. Provision of inter- and intra-seasonal weather and climate outlooks is necessary, wherever possible to a reasonable accuracy, to minimize risks (Stigter et al., 2016b).

Farm management skills were one other area of concern that was identified within the study area, as elsewhere in Africa (Stigter et al., 2005). Therefore, agro-advisories tailor made for the farmers ought to address such skills for a specific farmer to overcome poor productivity. Agro-advisories were designed in a manner that it was user-friendly, addressed relevant issues per farmer or an area. Therefore, the application of agrometeorology on-farm is a concept that needs to be well-taught to the farmers and other users (Stigter et al., 2005). The study groups played a pivotal role to establish trust amongst stakeholders toward the application of agrometeorological knowledge and services. Facilitation of knowledge transfer to the end-users remains the ultimate activity concerning addressing and eliminating unnecessary barriers to good productivity. Therefore, the development of tailor-made advisories and services must be the first priority in creating a learning situation for farmers about environmental conditions for improved decision making towards sustainable agriculture (Winarto and Stigter, 2016).

More on the South-Western Free State as a case study

The south-western Free State provides a workspace, not unique, in which to assess how agrometeorological advisories are being developed, disseminated, perceived and used at a provincial and local scale. In the study area, agrometeorological knowledge is developed based on weather forecasts, climate prediction, crop suitability and long-term climate data. The analysis of long-term climate data indicates that the crop growth season starts somewhere November-December-January. Such knowledge enables the farmers to choose the most suitable cultivar for a given or potential planting date. The high dependence on rainfall for crop production in the south-western Free State and in Sub Saharan Africa as a whole requires more reliable agrometeorological weather forecasts and climate predictions for farmers for their management and coping operations. Increasing climate variability, as a consequence of climate change (IPCC, 2007; Stigter, 2015; Stigter and Ofori, 2014a), under rainfed conditions can have devastating impacts on plant growth and developmental stages, resulting in poor crop yield of the varieties in use, worsening poverty and deepening food insecurity.

According to for example Thornton and Cramer (2012), Thornton (2012) and Thornton et al. (2007), the effect of climate change will also have adverse impacts on crop production because of an increased local mean temperature by 1 to 3°C before the end of this century. Rainfall distribution plays a big role in plant developmental stages and modifies the whole process of plant growth. During prolonged dry spells drought effects occur, while water logging is experienced during periods of extensive rainfall. Drought occurrences can affect developmental stages positively or negatively, based on the crop development stage. As part of our learning approach during engagements, farmers discussed different developmental stages. Based on the predicted seasonal conditions, farmers were advised to shift planting dates, change cultivars and observe the weather forecast closely for reduction of crop losses. It may become advisable for farmers to opt for shorter growing season cultivars or to plant drought tolerant varieties (Komba and Muchapondwa, 2015). During extensive rainfall events, water logging may occur depending on the type of soils in the area. In this study area most farms were located on high clay soils. During water logging, stress also inhibits water uptake, since the rooting zone becomes 100% saturated with water and this causes a lack of oxygen necessary for root development and respiration (Jackson, 2004).

Crop selection is yet another very important factor in farming systems. Therefore, as one of the other science based services than weather forecasts and climate predictions, farmers were advised to select alternative suitable crops derived from a crop model. The Ehlers Crop Suitability Zones (ECSZ) system was used for crop selection (Ehlers, 1988). This crop selection system was used to guide agricultural production as a function of weather and soil conditions, with considerations of crop management. Using this crop simulation model, the suitable crops are selected with consideration of temperature requirements. The ECSZ database was developed for South African conditions (Ehlers, 1988). It is used for crop suitability selection using the seasonal temperature requirements of the crop against a predefined zonal seasonal climate index. It is a web-based system that requires the Arc-Map tool from a Geographical Information System (GIS) to draw up maps according to a zonal seasonal climate index (Zuma-Netshiukhwi, 2012).

The Ehlers crop specifications data are available for 400 crops that can be planted in suitable specified zones as described according to this seasonal climate index (Ehlers, 1988). The Ehlers zone model was chosen for its provision of a high number and variety of crops that a user can choose from. Therefore, the farmer can consider a variety of crops to be included in his/her farming system and sequential farming can also be adapted for producing for own consumption and/or income generation. The zones are identified by four digits, e.g. 7714 (Figure 1). Areas with similar seasonal climate index are identified with the same colors; different colors represent different altitudes and seasonal climate indices. This makes it easier to identify the optimal and sub-optimal suitabilities of crops per zone (Figure 1). Seven different suitability zones were identified for a wide range of crops for the study area. They were as follows (Figure 1): zone 4614 covers a very small area of Mantsopa Local Municipality in the far east of the catchment and the examples of suitable grain food are hemp, millet and tefgrass; zone 5714 covers parts of Mantshopa, Naledi and Kopanog Local Municipalities and the most suitable grain food are oats, hemp and winter wheat; zone 6714 covers parts of Masilonyana, Mangaung and Kopanong and the most suitable grain food are maize, barley, oats; zone 7714 is the largest zone and covers the western part of Masilonyana, Mangaung and Letsemeng Local Municipalities with barley, maize, Indian millet, summer and winter wheat suitable grain crops; zone 7725 covers the south-eastern area of Sol Plaatjie Local Municipality and stretches along the Modder River in the low lying valley region from the west to about 20 km past Koffiefontein town with maize, summer and winter grain crops as the most suitable; zone 8815 forms part of Siyancuma and Letsemeng Local Municipalities with rice, maize, barley and millet suitable grain crops; and zone 8825 forms part of Sol Plaatjie and Siyancuma Local Municipalities and the most suitable grain crops as maize, rice, barley and millet.

The outputs of suitable crops were incorporated into agro-advisories informing farmers of alternative crops that can be profitable. The south-western Free State region has a wide range of crops that can be used for diversification. Crop selection is a first step towards the development of meaningful agro-advisories. The ECSZ system selects a range of crops for each zone and also classifies each crop as optimal or sub-optimal. The crops as extracted from the ECSZ system were grouped as follows: vegetables, herbs, grain food, oil seeds and fruits. These alternative crops were adopted by most farmers. Some of the crops from the ECSZ system were not accepted by the farmers, such as mango, pineapple and paw-paw. These crops were rejected due to the fact that south-western Free State is not only a relatively cold area but also semi-arid, which made farmers doubtful.

Agro-advisories were developed to guide the farmers based on the seasonal conditions for 2009/2010,

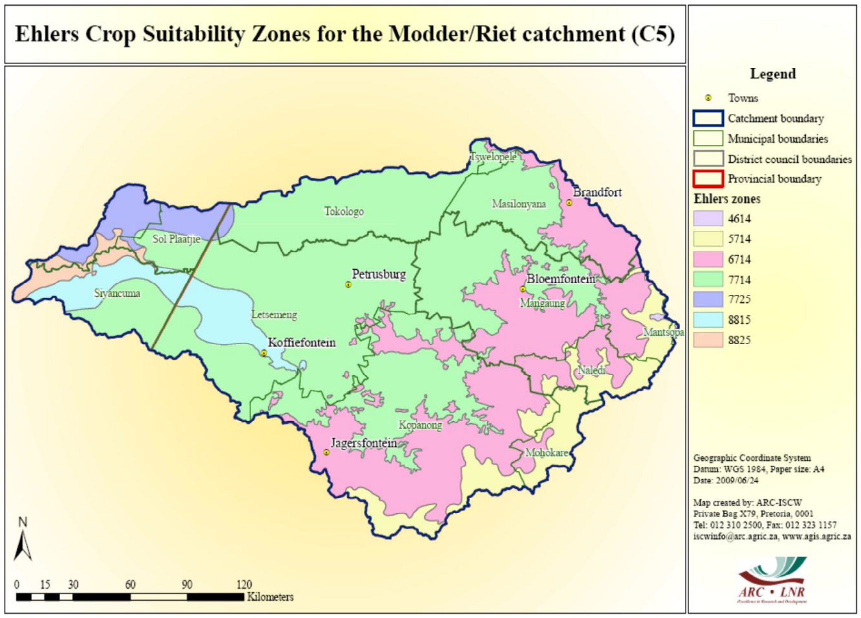

Figure 1. The study area map showing different zones for alternative crops.

whereby for October-November-December (OND), November-December-January (NDJ) the rainfall predictions were below-normal, but for January-February-March (JFM) above-normal rainfall was expected. These agro-advisories were on crop type selection, cultivar selection, planting date selection and management strategies. The advisory recommended that the farmers should strictly consider late planting, preferably within the last week of December 2009, following the 14-days prediction prior to engaging to agricultural daily activities. The best scenarios given to the famers under early below-normal but late above-normal rainfall conditions were to consider planting cultivars with short maturing times, increase plant population and control weeds more often. However, not all farmers took heed to delayed planting, For example, some farmers planted on 30th November 2009 and harvested only about 1 to 2 ton/ha of maize, while farmers who planted on 27 December 2009, three days before the actual onset of rainfall, harvested 2 to 3 ton/ha of maize in July 2010 under rainfed conditions.

A shift from only using traditional knowledge was observed by the agrometeorologists since during discussions at workshops and on-farm visits, famers were more interested to discuss agrometeorological knowledge, agro-advisories and services [51]. During interaction with the farmers, we noted successful use and limitations of local traditional knowledge as well as scientific knowledge (Zuma-Netshiukhwi et al., 2013). The request for agrometeorological knowledge, agro-advisories and services increased (Stigter, 2011). These farmers were taught well on how to interpret rainfall maps and on the application of rainfall knowledge for on-farm decisions (Winarto and Stigter, 2016). Limitations were due to methods of knowledge dissemination since most farmers have no access to e-mails and internet. Also the district intermediaries or extension officers were not well skilled in using weather forecasts and climate predictions or other knowledge to create advisories/services (Stigter et al., 2016a). However, after all, the availability of weather forecasts and climate predictions as well as other climate services for agriculture, as exemplified above, to all types of farmers, led to noticeable changes in their decision making and to improvements in their management practices (Stigter and Winarto, 2015a, b).

Case study within this case study: Animal husbandry farmers

Small and large livestock farmers were identified during the diagnosis stage of the research programme of our study. Such farmers were involved in pig, poultry, sheep, goat, cattle and horse farming. There is a huge increase in public demand for animal products for local consumption in Africa (Nardone et al., 2010). But, worldwide a scourge of climate change has been observed by farmers and scientists alike. This causes noticeable shifts in local climate conditions, resulting in severe impacts on local agriculture. More frequent warm spells, heat waves and heavy rainfall have been estimated to reach confidence level >90% (IPCC, 2007). The effects of changing climate conditions on soil erosion and fertility, on water scarcity (most recently the very serious 2015/2016 drought), on grain yields, on fodder quality, on outbreak of diseases and insect pests weaken animal production.

In the south-western Free State, under mixed farming systems manure is used for fertilizer on cultivated land to improve soil nutrient and organic matter status. The just mentioned diverse climatic conditions not only negatively influence animal husbandry directly but also have an impact on crop and pasture production which indirectly affects animal growth and production (Nardone et al., 2010). Therefore, provision of agrometeorological knowledge, agro-advisories and services assists to make decisions that favor the increase of stock productivity per head and improve the sustainability of animal production. As an example, an appreciable number of cattle and sheep were recorded dead during the above-normal rainfall season in 2009/2010 in the Free State province of South Africa, as a result of a vector borne disease called rift valley fever (The South African Health News Service, 2010). Should the farmers have known about forecasted weather and predicted climate conditions and would they have received timely advisories, they would have been able to vaccinate their stock and to relocate animals from near wetland areas, swamps and salt pans to much drier feedlots (Zuma-Netshiukhwi, 2012).

Another case study within this case study: Agroforestry

It is also important to discuss a case study of agroforestry, which is the association of trees with farming practices. It is the art and science of cultivating woody perennial plants such as trees in association with crops and/or animals (Kinama et al., 1995; Stigter, 2010; Torquebiau, 2000). Agroforestry is known as an archetype of traditional agriculture. According to Molua (2005), agroforestry is a form of sustainable land use that combines trees and shrubs with crops and/or livestock in ways that increase and diversify farm and forest production while also conserving natural resources. It is an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock. And these days we also look at the positive carbon sequestration involved (Stigter, 2010).

The often countrywide deforestation and increasingly intensive use of land to sustain a growing population has increased soil erosion, scarcity of tree products and environmental degradation, it has lowered soil fertility, and therefore reduced agricultural productivity (Neupane et al., 2002). Agroforestry is considered a sustainable agricultural system. Therefore, it is being widely promoted all over the world but especially in sub-Saharan Africa (Thangata and Alavalapati, 2003). Agroforestry and the complex relationships between agriculture and forestry deliver a common perception that agroforestry is closer to agriculture than to forestry (Torquebiau, 2000) but in a landscape and production view they can often be hardly differentiated (Stigter and Winarto, 2015a, b). Field experience indicates a structural classification of agroforestry which is divided into different categories as follows: crops under tree cover, agroforests and agroforestry in a linear arrangement, animal agroforestry, sequential agroforestry and minor agroforestry techniques (Torquebiau, 2000).

Torquebiau (2000) and Stigter et al. (2005) show complementary that agroforestry advantages can be described as the provision of multiple products (e.g. food, wood, fodder, mulch, fibers, medicines) and services (e.g. soil fertility maintenance and erosion control, microclimate improvement, biodiversity enhancement, watershed protection) by the trees. For example, most farms and farm houses and animal shelters are surrounded by different types of trees such as Eucalyptus, Blue gum, Wattle, Acacia and other types. These trees are used as shelterbelts, windbreaks as well as for inter-cropping and for animal shade. Agroforestry constraints mainly concern potential competition between trees and crops for water, light and nutrients as well as for farm resources such as land or labour. Integration of trees with agricultural activities comprises of well-established farming practices which have been widely studied for the past three to four decades. For example the parklands of Africa are considered “the largest single agricultural land use in sub-Saharan Africa” (Vandenbelt, 1990). Yet another example of agroforestry is the grazing of animals in plantation forests as well as the herding of animals in rangelands with more or less dispersed trees (Stigter, 2010; Von Maydell, 1987).

The area selection in our study was based on the motives to assess the feasibility of agrometeorological knowledge and agro-advisories/services applications for agricultural practices with agroforestry. These farms or households were randomly selected for questionnaire surveys. In this questionnaire, agroforestry related questions were incorporated to assess the farmer’s perceptions and their agroforestry practices in the selected study area. Amongst all interviewed farmers, agroforestry formed part of their farming systems. Examples are perennial trees that are used for shades for animals, using trees planted where cash crops are planted, or fruit trees and other indigenous types of trees used for fuel. Therefore agroforestry in the south-western Free State forms an integral part of the farming systems. Agroforestry is also delivering part of supplementary sources of food, fodder, fuel-wood and timber by maintaining some naturally grown trees on farmlands. There is a continuous tradition in the south-western Free State of mixed inter-cropping of fruit trees, exotic trees with grains and vegetables (Zuma-Netshiukhwi, 2012; Stigter, 2010).

Use of weather and climate knowledge in agriculture

The National Agrometeorological Committee is a body of different stakeholder that provides seasonal outlooks for the whole country in South Africa. The outlooks entail seasonal predictions and generalized recommendations for farming activities. Therefore, the development of agricultural recommendations based on the given seasonal forecasts becomes very imperative and a necessity for the agricultural sector. Downscaling of seasonal predictions to a lower resolution, for whatever it is worth (Hashigonta, 2011), is wanted for the selection of activities attuned to a specified given environment. However, use of ENSO seasonal climate predictions appears presently more successful (Stigter et al., 2016b). When skills as well as transfer language and other extension are optimal, this leads to the development of tailor-made agro-advisories which are a requirement to address specific needs of the farmers. These recommendations are made on the basis that farmers have access to basic agricultural technologies, such as, machinery: tractor, ploughs, discs, rippers; crop types and crop varieties; fertilizer requirements and its application; integrated pest management; supplementary irrigation. Seasonal boundaries assist farmers to identify the period in which rainfall onset and cessation are expected to become apparent. Seasonal prediction is crucial for planning in advance by crop producers, animal husbandry, agroforestry and fisheries. It is mainly crucial for setting boundaries in between the seasons and determination of suitable agricultural practices.

Seasonal prediction is usually categorized into three classes of above normal, near normal and below normal. Therefore, agricultural decision making is guided by these predicted rainfall conditions. The study group approach is a crucial means of engaging with the farmers for knowledge dissemination and knowledge exchange. The study group meetings elicited options that farmers thought were weather and climate sensitive and that they considered in receipt of agro-advisories. Suggestions alluded by the farmers were based on crop production, animal husbandry and other non-agricultural activities. Decisions such as adopting water conservation techniques, changing to drought tolerant cultivars, minimizing planting density, selling of older livestock, purchasing of feed well in advance, might only be considered when below normal rainfall predictions are prevalent.

The decisions mentioned by the farmers were operational strategic decisions that reflected long term options and operational tactical decisions that reflected short term options. Such options and preferential choices play a critical role in coping with agricultural risk depending on the appropriateness of such decisions. These decisions are also guided by indigenous knowledge that has been accumulated by farmers for a number of years and is available to all walks of our farmers. The propensity of farmers to expect favorable climatic conditions for all seasons and years might lead to poor management, economic loss and food insecurity. Predictions guide away from this tendency. Additionally, farmers are prepared to learn new technologies, make new decisions that produce good profit, since most farmers are dependent on on-farm produce to sustain households.

Additionally, agricultural decisions, strategies and responses to climatic conditions differ from region to region, farmer to farmer and are centered given the farmer's resources, agricultural enterprises practiced, farmer's skills, weather forecasts and seasonal predictions and other climate services for agriculture available. More exposure, availability and training related to weather forecasts and climate predictions as well as other climate services is necessary to ensure that farmers become faced towards applicability of knowledge and towards improving informed agricultural decision making.

CONCLUSIONS

There is a great need for the extension of agrometeorological knowledge to the end-users such as farmers, extension officers, and policy makers for improved decision making. Provision of such knowledge provided evidence that our farmers need science-based knowledge such as in reliable weather forecast and climate predictions as well as other above exemplified climate services in agriculture. Access and availability of such knowledge to end-users remains a huge challenge.

Therefore, development of tailor made agro-advisories remains yet another challenge in developing countries such as South Africa and many others. As shown by our south-western Free State case study, thorough qualitative research to ascertain the needs of the farmers that relate to agrometeorological knowledge and services is a first step that leads to the development of tailor-made and farmer friendly agro-advisories.

This paper affirms that application of weather forecasts and climate predictions and other climate services in agricultural decision making pays off provided the knowledge given is reliable and accurate. Weather forecasts and climate predictions accuracy and reliability are therefore among the utmost critical factors in determining the benefits of such knowledge to the end-users such as farmers. The uptake of agrometeorological knowledge differed from farmer to farmer, but to the extent that also small scale farmers benefited from implementing some of the decisions that were discussed during study group meetings. This reduced food insecurity within their households. Well-resourced farmers had better and deeper understanding of agrometeorological knowledge, weather forecasts and climate prediction, as well as of other climate services. This group of farmers was observed to have higher yield improvements.

The use of weather forecasts, climate predictions and other climate services such as ECSZ and improved management skills was beneficial. The ECSZ system provided a range of crops for each zone and laid a platform for a variety of choices for farmers, this knowledge was used to develop tailor-made agro-advisories. Crop selection varied from vegetables, herbs, grain food, oil seeds and fruits. These alternative crops were adopted by most farmers and managed according to their improved skills. All other climate services that were generated were also profitable for the farmers.

Agrometeorological knowledge and services have a noticeable impact on all levels of farmers. The National Agrometeorological Committee has to review their dissemination strategies and to ensure that the knowledge reaches farmers and the services get established in a way that stimulates feed-back from the farmers.

REFERENCES

Archer ERM, **2003**. Identifying underserved end-user groups in the provision of climate information. Bull Am Meteorol Soc, 84: 1525-1532.

Aw-Hassan A, **2008**. Strategies for Out-Scaling Participatory Research Approaches for Sustaining Agricultural Research Impacts. Dev Pract, 18(4/5): 564-575.

Baethgen WE, Carriquiry M, Ropelewsk C, **2009**. Tilting the odds in maize yields. Bull Am Meteorol Soc, 2: 179-183.

Berggren R, **1978**. Economic benefits of climatologically services, Technical note. Geneva: World Meteorological Organization. pp 45.

Calanca P, **2014**. Weather forecasting applications in agriculture. Encyclopedia of Agriculture and Food Systems. pp: 437-449.

Day D, Dosa M, Jorgensen C, **1995**. The transfer of research information within and by multicultural teams. Informat Process Manag, 31: 89-100.

Ehlers JF, **1988**. Ekologise beplanning van gewasse (Ecological Planning of Crops). Department van Landbou-tegniese Dienste, Transvaalstreek, pp 1-88.

Erbaugh MJ, Donnemeyer J, Amujal M, **2007**. Assessing the impact of farmer fields schools on IPM in Uganda. In: Proceeding of the 23rd AIAEE Conference, Polson, Montana.

Hashigonta S, **2011**. Downscaling and its limitation on climate change impact. http://www.slideshare.net/cgiarclimate/5-sepo-ccafs (viewed on the 26 November 2012).

IPA, **2012**. Fighting poverty with innovation, evidence and action. http://poverty-action.org/project-evaluations/search (29 November 2012).

IPCC, **2007**. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.) IPCC, Geneva, Switzerland. pp 104.

Jackson MB, **2004**. The impact of flooding stress on plants and crops. http://www.plantstress.com/articles/waterlogging_i/waterlog_i.htm (viewed January 2013).

Kinama JM, Nganga JK, Torquebiau E, Gichuki FN, Stigter CJ, **1995**. Effect of microclimate, soil and water conservation of contour hedgerows on sloping lands for sustainable land use in Machakos District, Kenya, in: C.J Stigter, F.J Wangati, J.K Nganga, D.N Mungai (Eds.), The TTMI Project and the Picnic Model Wageningen Agricultural University, Wageningen (1995), pp. 136–140.

Komba C, **Muchapondwa** E, **2015**. Adaptation to climate change by smallholder farmers in Tanzania. Environment for Development, Discussion Paper Series, 15-12, 45 pp.

Lyne M, **Darroch** M, **2003**. Land Redistribution in South Africa Past Performance Future Policy. In The Challenge of Change Agriculture, Land and the South African Economy. Edited by LiebNieuwoudt and Jan Groenewald pp. 65.

Molua EL, **2005**. The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. Forest Policy Econ, 7: 199-211.

Mukhala E, **2000**. An evaluation of communication effectiveness between meteorological scientists and farmers in the Free State province. M.A. thesis, University of the Free State, Bloemfontein, South Africa.

Murthy VRK, **2008**. WMO-ANGRAU-DST sponsored Roving Seminars on Weather, Climate and Farmers. http://www.agrometeorology.org/topics/needs-for-agrometeorological-solutions-to-arming-problems/report-on-the-project-entitled-201cwmo-angrau-dst-sponsored-roving-seminars-on-weather-climate-and-farmers.

Murthy VRK, **Stigter** CJ, **2004**. Stigter's diagnostic conceptual framework for generation and transfer of agricultural meteorological services and information for end users. In: Agrometeorology in the new millennium - perspectives and challenges. Proceedings of the Second National Seminar of the Association of Agrometeorologists in India, Ludhiana. http://www.agrometeorology.org/files-folder/repository/murhty_stigter.pdf.

Nanja DH, **2011**. Mujika Personal Stories: Climate Learning, Changing Livelihood. INSAM http://www.agrometeorology.org/files-folder/repository/MujikPersonalStories.pdf.

Nanja DH, **Walker** S, **2011**. Handbook for Community Agrometeorological Participatory Extension Services. INSAM http://www.agrometeorology.org/filesfolder/repository/HandbookCAPES.pdf.

Nardone A, Ronchi B, Lacetera N, Ranieri MS, Bernabucci U, **2010**. Effects of climate changes on animal production and sustainability of livestock system. Livestock Sci, 130:57-69.

Neupane RP, Sharma KR, Thapa GB, **2002**. Adoption of agroforestry in the hills of Nepal: a logistic regression analysis. Agric Syst, 72(3): 177-196.

O'Brien K, Sygna L, Naess LO, Kingamkono R, Hochobeb B, **2000**. Is information enough? User responses to seasonal climate forecasts in Southern Africa. Report No. 2000-03, CICERO, Oslo.

Stigter CJ, **2005**. Building stones of agrometeorological services: selected contemporary science and understanding of prevailing policy environments, Opening key note lecture at the FPEC Symposium, Fukuaka, Japan. J Agric Meteorol, 60: 525-528.

Stigter CJ, **2010**. Applied agrometeorology. Springer, Heidelberg Verlag Berlin., xxxviii + 1101 pp.

Stigter CJ, **2011**. Agrometeorological services: Reaching all farmers with operational information products in new educational commitments. CAgM Report 104, WMO, Geneva, 37 pp.

Stigter CJ, **2015**. Agroforestry and (Micro) Climate Change. Chapter 5 in Chin Ong, Colin Black and Julia Wilson (Eds.) Tree/Crop Interactions (2nd edition): Agroforestry in a Changing Climate. CABI, Wallingford, UK, 119-146.

Stigter CJ, **Ofori** E, **2014a**. What climate change means for farmers in Africa. A triptych review. Middle Panel: Introductional matters and consequences of global warming for African farmers. Afr J Food Agric Nutr Dev, 14(1): 8420-8444.

Stigter CJ, **Ofori** E, **2014b**. What climate change means for farmers in Africa. A triptych review. Left Panel: Increasing climate variability and a response approach for African farmers. Afr J Food Agric Nutr Dev, 14(1): 8445-8458

Stigter CJ, Oteng'i SBB, Oluwasemire KO, Al-amin NKN, Kinama JM, Onyewotu LOZ, **2005**. Recent answers to farmland degradation illustrated by case studies from African farming systems. Annual Arid Zone, 44(3):255–276.

Stigter CJ, **Winarto** YT, **2015a**. Agrometeorological Learning: Exchanges of traditional, more recent empirical and scientific knowledge between farmers, extension intermediaries and scientists. Paper based on a PowerPoint presentation used in preliminary form in two local Knowledge Sector Initiative (KSI, Australia) Workshops [BelajarAgrometeorologibersamaPetani: MengapaPerluDilembagakan? (Learning Agrometeorology with Farmers: Why is it Necessary to be Institutionalized?)], in Indramayu, West Java, 29 October and Selong, Lombok, 5 November. In final form in an Australian Research Center Workshop on "Environmental Education in Indonesia" in Depok on 13 and 14 December. Science Field Shops Project of the Cluster Response Farming to Climate Change, Department of Anthropology, Centre for Anthropological Studies, Faculty of Social and Political Sciences, Universitas

Indonesia, Depok, with Agromet Vision (Netherlands, Indonesia and Africa). Will be used in its final form to be published in a book based on the December conference in Depok. Is already available on ResearchGate.

Stigter CJ, **Winarto** YT, **2015b**. Knowledge Transfer and Communication Technologies (KTCTs) for sharing innovative technologies and practices: Window shopping for Science Field Shops. Paper from a PowerPoint presentations used (in preliminary form with shorter title) in a National Knowledge Systems Initiative (KSI, Australia) Workshop “Science Field Shops: Can We Buy Time by Using Existing Knowledge with Farmers to Adapt to Climate Change?", and (in final form) in an International Programme (KSI) Workshop “Agrometeorological Learning as Policy Learning: Part of a Crucial Rural Response to Climate Change” (both in Depok, West Java, respectively on 26 August and 16 December). Science Field Shops Project of the Cluster Response Farming to Climate Change, Department of Anthropology, Centre for Anthropological Studies, Faculty of Social and Political Sciences, Universitas Indonesia, Depok with Agromet Vision (Netherlands, Indonesia and Africa). Will be used in a final form to be published in a book based on these conferences. Is already available on Research Gate.

Stigter CJ, **Winarto** YT, **2016**. Climate prediction for farmers: should we laugh or should we cry? Chapter 2 in Y.T. Winarto (Ed.) KrisisPangandan 'SesatPikir': MengapaMasihBerlanjut? [Food Crises and “Wrong Mind Set”: Why is it still Going on?], Indonesian Academy of Sciences, Jakarta, 13-20, in press.

Stigter CJ, Winarto YT, Wicaksono MT, **2016a**. Science Field Shops: An innovative agricultural extension approach for adaptation to climate change, applied with farmers in Indonesia. Chapter 21 in: Walter Leal Filho, Kathryn Adamson and Rachel Dunk (Eds.) Implementing Climate Change Adaptation in Cities and Communities. Series “Climate Change Management”. Springer International Publishing, Switzerland, in press.

Stigter CJ, Winarto YT, Wicaksono MT, **2016b**. Towards Enhanced Resilience: Monthly Updated Seasonal Rainfall “Scenarios” as Climate Predictions for Farmers in Indonesia. Written in the context of the World Symposium on Climate Change Adaptation, Manchester, UK, 2-4 September 2015, Session 4: Climate Change Adaptation, Resilience and Hazards. In: Walter Leal Filho, Haruna Musa, Gina Cavan and Paul O´Hare (Eds.). Climate Change Adaptation, Resilience and Hazards. Springer International Publishing Switzerland, in press.

Stigter K, Winarto YT, Ofori E, Zuma-Netshiukhwi G, Nanja D, Walker S, **2013**. Extension agrometeorology as the answer to stakeholder realities: Response farming and the consequences of climate change. Special Issue on Agrometeorology: From Scientific Analysis to Operational Application. Atmosphere, 4(3): 237-253.

Stigter CJ, **2016**. A decade of Capacity Building through Roving Seminars on Agro-meteorology/-climatology in Africa, Asia and Latin America: From agrometeorological services via climate change to agroforestry and other climate-smart agricultural practices. Written in the context of the World Symposium on Climate Change Adaptation, Manchester, UK, 2-4 September 2015. In: Walter Leal Filho, Rachel Dunk and Sam Illingworth (Eds.) Information, Communication, Education and Training on Climate Change. Springer International Publishing Switzerland, in press.

Thangata PH, **Alavalapati** JRR, **2003**. Agroforestry adoption in southern Malawi: the case of mixed intercropping of *Gliricidia sepium* and maize. Agric Syst, 78: 57–71.

The South African Health News Service, **2010**. http://www.health-e.org.za/2010/04/22/two-more-people-die-from-rvf.

Thornton P, **2012**. Recalibrating Food Production in the Developing World: Global Warming Will Change More Than Just the Climate. CCAFS Policy Brief no. 6. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at www.ccafs.cgiar.org.

Thornton P, **Cramer** L, **2012**. Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR’s mandate. CCAFS Working Paper 23. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), 199 pp. http://hdl.handle.net /10568/21226.

Thornton P, Herrero M, Freeman A, Mwai O, Rege E, Jones P, McDermott J, **2007**. Vulnerability, climate change and livestock—research opportunities and challenges for poverty alleviation. SAT eJournal, 4(1):1–23.

Torquebiau EF, **2000**. A renewed perspective on agroforestry concepts and classification. Life Sci, 323: 1009-1017.

Valente TW, **1995**. Network models of the diffusion of innovations, Hampton Press, Creekil, NJ.

Vandenbelt RJ, **1990**. Agroforestry in the semiarid tropics, in: K.G MacDicken, N.T Vergara (Eds.), Agroforestry Classification and Management. Wiley, New York, pp. 150–194.

Von Maydell HJ, **1987**. Agroforestry in the dry zones of Africa: past, present and future, in: H.A Steppler, P.K.R Nair (Eds.), Agroforestry, a Decade of Development ICRAF, Nairobi, pp. 89–116.

Winarto YT, **Stigter** CJ, **2016**. Incremental learning and gradual changes: "Science Field Shops" as an educational approach to coping better with climate change in agriculture. In: Lynn Wilson and Carolyn Stevenson (Eds.) Promoting Climate Change Awareness through Environmental Education. IGI Global (Information Science Reference), Hershey, USA, 59-93.

World Bank, **1998**. World Development Report 1998/1999: Knowledge for Development. New York: Oxford University Press. © World Bank. https://openknowledge.worldbank.org/handle/10986/5981 License: CC BY 3.0 IGO.

Ziervogel G, **Downing** TE, **2004**. Stakeholder networks: Improving seasonal climate forecasts. Climate Change, 65: 73-101.

Zuma-Netshiukhwi GNC, Stigter K, Walker S, **2013**. Use of traditional weather/climate knowledge by farmers in the south-western Free State of South Africa: Agrometeorological learning by scientists. Journal of Atmosphere, 4(4): 383-410.

Zuma-Netshiukhwi GNC, **2012**. The Use of Operational Weather And Climate Information in Farmer Decision Making, Exemplified for the South-Western Free State, South Africa. PhD Dissertation. University of the Free State-Western Free State of South Africa: Agrometeorological Learning by Scientists. Special Issue on Agrometeorology: From *Scientific Analysis to Operational Application. Atmosphere*, 4: 383-410.

Citation: Zuma-Netshiukhwi GNC, Stigter KCJ, Walker S, 2016. Improving agricultural decision making using weather and climate information for farmers, south-western Free State, South Africa. Net J Agric Sci, 4(4): 67-77.