The use of a weather analogue model to manage seasonal variability

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Maize production in the Highveld Ecoregion of South Africa has a CV of 30%. Contributing to this is the variable rainfall and use of marginal soils. In an average and above average rainfall season marginal soils will produce adequate maize yields for rural upkeep. However, in below average seasons these soils produce little or no yields that put an enormous strain on the resource poor farmer. If the farmer knows before the season starts that it is going to be dry he could adapt his management practises accordingly. Seasonal forecasting is such a tool and this paper describes the development and use of the Weather Analogue Model Seasonal forecasting software. Seasonal forecasts, using weather data of the current season and historical weather files is made possible.

This software is able to work on different scales. The researcher on a research station is able to input his weather data manually and then go through the menus to do a seasonal prediction or it could be fully automated to run within a GIS framework to do regional season predictions.

By linking a seasonal weather predictor with a simulation model it is possible to give an indication for the best bet production practises for a specific rainfall season, thus Site Seasonal Specific Management practises. The weather analogue is such a seasonal weather predictor program that it uses analogue methodology to select the five closest seasons to this particular season up to date. Five files are then generated with the current years weather data and completing the season with the weather data of each of the selected five seasons.

The five predicted seasons are then used to simulate different management scenarios that will produce the best bet management practise for that particular season. Thus managing the dry season, and rather be pre-emptive than reactive in drought management.

Introduction

It is essential for African Countries to develop a scientific understanding and techniques to shift from crisis drought management to risk management (Tendese, 1998). This is a necessity for sustainable development.

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The economy of the rural Highveld Ecoregion is based on agriculture. Since 70% of the arable land on the Highveld is planted to maize, and it produces 90% of the yield of South Africa, it plays an important socio-economic role within the agricultural community. Any policies that have an influence on maize production and land use within this Ecoregion will influence sustainability and rural development. Maize marketing in the Highveld region was transformed from a one-channel marketing system to a free marketing system in 1997. The Maize Board was the only marketing channel and the Minister of Agriculture had to approve the maize prize, after the announcement of the February yield forecasting figures by the National Yield Estimation Committee. The change towards a free marketing system resulted in little or no protection from imports. Current maize prices are determined by supply and demand.

South African maize production has shown an upward trend from 1951 to 1981, followed by a downward trend in recent years (Fig 1). The upward trend may be ascribed to the change from open-pollinated varieties to high yielding cultivars, improved fertilizer use, the availability of chemical weed control and advances in management practices. However, the observed increase in yield corresponded with an increased standard deviation. One possible explanation could be climatic changes that have taken place, which enhanced variability in rainfall. The ¯ -symbol in Figure 1 indicates drought induced low yields in the Highveld Ecoregion associated with El Niño. A combination of extreme climatic conditions, rising input costs and unstable maize prices makes it increasingly difficult to produce maize economically with existing production systems. Maize production on the Highveld Ecoregion is not sustainable and it is developing into an economical disaster.

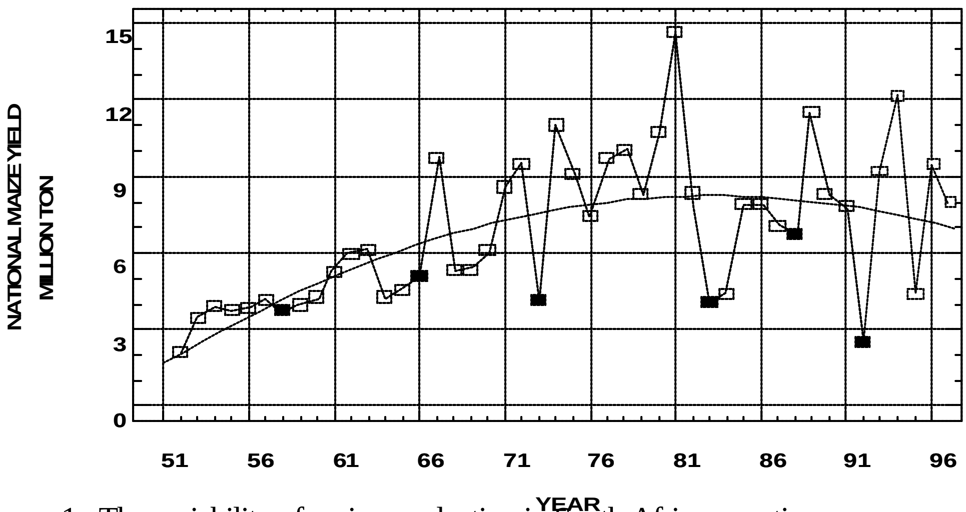

Figure 1. The variability of maize production in South Africa over time.

Existing NARS do not have the tools to take the adequate present day research information, on site-specific level, to an Ecoregional scale to be used in the development of improved land use options, policies and management schemes.

For researchers to solve these problems an integrated approach is needed to deal with the available resources without negative environmental impact. Food security, but also economic food production, will affect future land use in this Ecoregion. Water availability, within this Ecoregion, is a particularly important but scarce resource, not only the amount of rainfall but also the variability between seasons. This phenomenon is illustrated by maize yields recorded in a trial at Ottosdal, RSA. During the 1990/1991 season a yield of 6 300 kg ha^{-1} was obtained, followed by 800 kg ha^{-1} in 1991/1992. Even under experimental conditions the 1991/1992 yield was lower than both the 2 000 kg ha^{-1} economical and the 900 kg ha^{-1} famine threshold levels. The 1991/1992 seasons was an El Niño season with disastrous effects in eastern and southern Africa. Waddington *et al*. (1997) indicated that South African maize production has a coefficient of variation (CV) of 30%. To counter this variability, researchers need to develop an early warning forecasting system that could indicate the probability of drought in a forthcoming season.

Tools such as crop modelling, GIS[2] and Interactive Multiple Goal Linear Programming techniques are well developed and proven instruments that enable a problem orientated Eco-regional approach (Rabbinge, 1995). Bouman *et al*., (1994), Thornton *et al.*, (1995), De Jager *et al.*, (1998) and Thornton *et al*. (1997) have indicated that a crop growth simulation model linked to a GIS system could be used as an early warning and for yield forecasting. This needs to be in combination with early seasonal indicators like the ENSO index[3], SOI[4], historical databases and analogue years (De Jager *et al.*, 1998). Experience in South Africa's Yield Estimating milieu has indicated that analogue years based on historical trend analysis could be used with reasonable levels of success. This was one of several methodologies used by the World Outlook Board in maize prediction for southern Africa.

[2] Geographical Information System
[3] El Niño - South Oscillation Index
[4] South Oscillation Index

As part of the Highveld Ecoregion project[5] this methodology was incorporated when a software package, the Weather Analogue Program (WAP), was developed.

This paper reports on the development of WAP and the concept how to use it in the management of seasonal variability.

Materials and Methods

The Weather Analogue Program (WAP) was developed to do seasonal predictions on a site level. WAP uses analogue methodology whereby, the up-to-date conditions of the present season, is compared to the five best fitting historical seasons in the database. The information is then presented in the form of a graph and a table. The search algorithm used, was proposed by Willmott (1982) as an "index of agreement" (D) of the form:

$$D = 1 - \left[\sum_{i=1}^{n} (Pi - Oi)^2 / \sum_{i=1}^{n} \left(|P'i| + |O'i| \right)^2 \right] \quad (1)$$

where $P'i = Pi - \bar{O}$ (average of the observed) and $O'i = Oi - \bar{O}$. The index (D) is intended to be a descriptive measure, and it is both a relative and bounded measure, which can be widely applied in order to make cross-comparisons between models. Each season is presented as the simulation output of a model with the current season as the observed values. WAP finds the best five models that fit the weather data of the current season the best.

This program has a user-friendly spreadsheet type of interface for data input and stores it in a standard format. WAP uses the DSSAT v3 & 3.5 ASCII format, and append the weather data of the current season to the historical weather datasets.

The program also export five files, all of them consisting of the up to date weather data of the current season and uses each of the five analogue years to complete a season. The program can be run via the keyboard or from an ASCII file used within a GIS framework.

[5] Funded by the Ecoregion fund, managed by ISNAR

Crop growth Simulation model (CERES-Maize).

CERES models for maize, sorghum, wheat, millet and barley were combined to provide a generic multi-crop CERES3, to run with a single set of codes, incorporating the development and growth sections for each individual model into a single module with a single soil component (Tsuji *et al*., 1994). According to Ritchie (1991) generic models should allow users to have more uniform procedures for validating models or to link with components not included in the generic model. The generic CERES3 (Hoogenboom *et al*., 1994) was used for the simulations, with modifications made as reported by Du Toit (1996). The program was adapted to run in the DSSAT v3.5 frame.

CERES runs from a control file that describes the experimental simulation trial. For South Africa such a trial consisted of 6 plantings at two-weekly intervals in combination with super short, short, medium and long growing seasons cultivars. All of these were in combination with a low medium and high plant population. Each of these treatments was then run for all five of the analogue weather files exported by WAP (Fig 2).

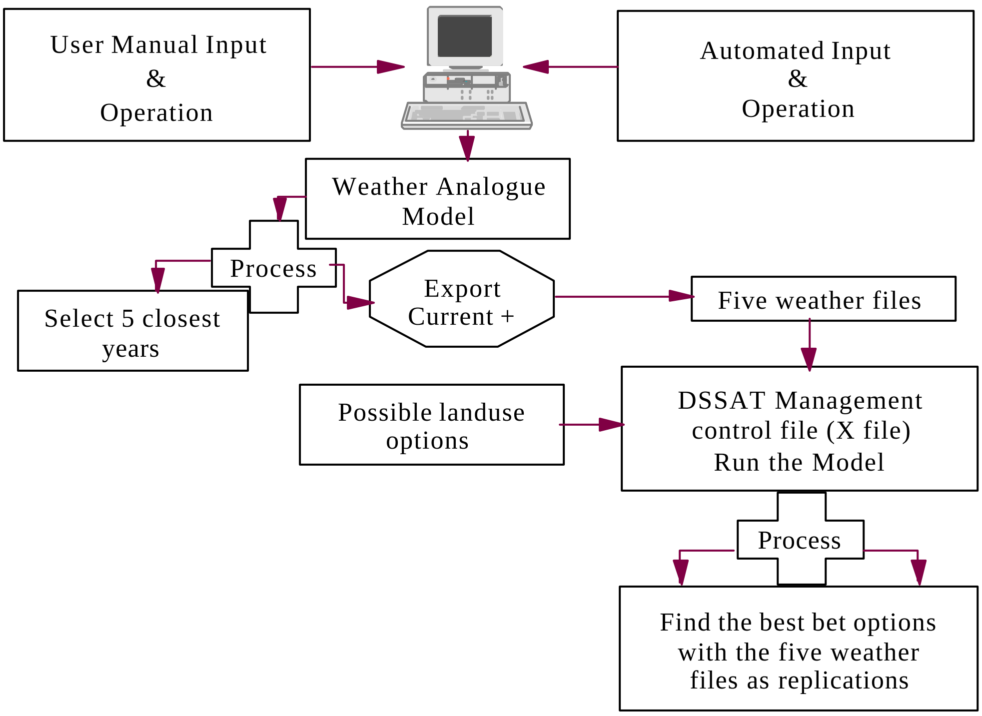

Figure 2. Flow diagram for the WAP crop growth simulation framework.

Results and discussions.

Differences recorded in yield between different planting dates and cultivar combinations are presented in Table 1 (Du Toit *et al.,* 1997). The difference between the highest and the lowest treatment was more than 4 000 kg ha^{-1}. The result is a mirror image of the recommendations for this particular area of the Highveld Ecoregion. If the farmer had used the recommended later planting date with a medium growing season length cultivar he would not have been able to recover his input costs, but had he opted for the combination of a long growing season cultivar with an early planting date, he would have made a healthy profit.

Table 1 Grain yield (kg ha^{-1}) and planting dates of six cultivars of various maturity classes (Phoenix trial, Potchefstroom).

	Maturity	***Planting dates***		
Cultivar	***Class***	***15/10/86***	***05/11/86***	***27/11/86***
PAN 394	Early	4 508	2 598	1 696
PAN 6364	Early	3 450	3 088	2 459
SNK 2244	Medium	3 429	3 767	2 038
PAN 473	Medium	3 401	3 322	1 799
TX 24	Late	5 323	3 351	1 214
PAN 6528	Late	3 726	2 668	2 063

This is an example of the kind of management challenges that faces the Highveld Ecoregion farmer. He not only has to cope with within seasonal variability but also with variability between seasons. WAP was developed to assist the farmer on how to manage this variability.

Much work has been done in this regard using ENSO as a seasonal indicator on how a season will deviate from the mean, or a refinement of this, the ENSO analogue years. Du Toit & Prinsloo (2001) reported on this and how it is used to manage seasonal variability. Both of these methodologies have a top down approach. In theory this information is freely available, while in practise it is just the opposite.

The strategy for the development of WAP was to develop methodology that would give seasonal prediction capabilities to a wider range of persons to do seasonal forecasting. At this stage some farmers are already using WAP for their own seasonal planning and seasonal forecasting.

WAP has already been distrusted to a wide range of countries (Fig 3). From experience the developers know that this methodology works in southern Africa, but are uncertain how this methodology would perform in other parts of the world.

Case studies: During a visit to Arusha, Tanzania, WAP was installed on the computer of Charles Lyamchai and a set-up done to do seasonal forecasting. The historical weather file was set-up until 1998 and the data from the 1999 season entered to determine if the disaster of that year in East Africa could be forecasted

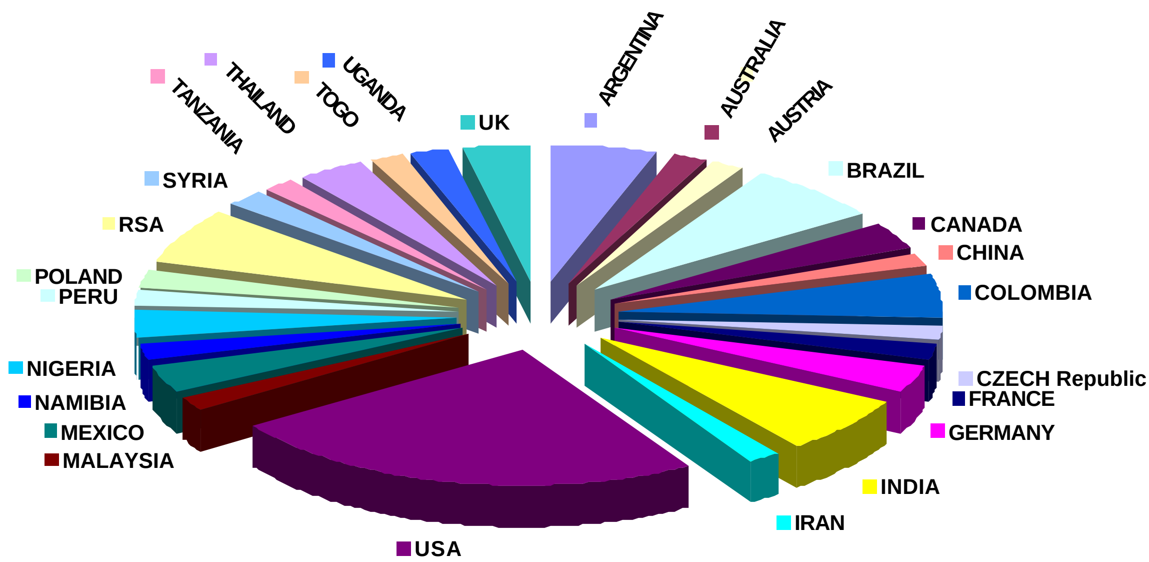

Figure 3. Distribution of the Weather Analogue Model to different part of the world.

early in the season. WAP scanned the database and selected two previous seasons of similar history. From the local knowledge that Charles Lyamchai had he could immediately recognise that the closest analogue years were drought years. Combining WAP seasonal forecasting with local knowledge empowers the user and adds value to the existing weather data as the basis of a site-specific early warning system.

The next level of use was where the simulation trial (Ottosdal, RSA) ass set up to run with the five analogue years as replications and the best bet options determined from these outputs. Alternatively the treatments can be ranked according to the yields and the treatments that are ranked in the top five of each of the analogue years. Yield simulation output is then selected as the best bet options. For more information see Du Toit & Prinsloo, (2001).

To be able to run the model within a GIS framework, WAP was developed to run without a keyboard from an ASCII file (Table 2). The Agricultural Research

Council-Grain Crops Institute (ARC-GCI) will incorporate this approach in the 2000/2001 maize yield estimation season as their output at the National Crop Estimating Committee.

Table 2. ASCII command file for the automated execution of the weather analogue program

Command	Description
AUTO	Run program without keyboard input
C:\WINDOWS\DESKTOP\Programs\Hei1.wth	Historical weather data file
C:\Windows\Aria1Tem.txt	Internal program file
C:\Windows\aria1tm3.txt	Current season weather file
C:\Windows\aria1tm2.txt	Internal program file
4	Witch climatic indicator (Rain)
S	Stop the program

The use of WAP within the INRM framework

The use of marginal soils in combination with variable climatic conditions is one of the problems in the management of soils as natural resource. During seasons with high yield potential the marginal soils will produce a profitable yield, but in the Highveld Ecoregion during average and below average seasons the opposite is true. While it is preferable that marginal soils be removed from any production system, in most farming systems the farmer is depended on this type of soil to survive. Using WAP, in combination with the crop growth simulation model, an early decision could be made in an expected drought season not to plant on the marginal soil or to adapt the management practises according to the low seasonal potential in combination with the marginal soils.

The use of WAP within the Highveld Ecoregion project.

WAP is one of the products of the Highveld Ecoregion project to improve sustainability on the short term by using Site Seasonal Specific Management practises and in yield forecasting. WAP development strategy was that it would be useful to users with a wide range of skill levels. A modified version of this program is at present being used in methodology to remove historical trends from yield estimations in South Africa.

Conclusion

The development phase of WAP had been completed and it is ready to be implemented and evaluated in the different usages for which it had been developed. The structure and logic of WAP enables ENSO, as early season indicator, to be implemented.

The primary advantage of WAP is that it adds value to historical weather data, as resource, and its most basic use is to structure weather data input.

While there are various references in the literature how seasonal forecasting could be used in the management of natural resources in pre seasonal planning or response farming, the authors know of no software that makes this concept easily accessible. WAP is an innovative tool that helps to manage seasonal variability.

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