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Grid-cell-based crop water accounting for the famine early warning system

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Abstract:

Rainfall monitoring is a regular activity of food security analysts for sub-Saharan Africa due to the potentially disastrous impact of drought. Crop water accounting schemes are used to track rainfall timing and amounts relative to phenological requirements, to infer water limitation impacts on yield. Unfortunately, many rain gauge reports are available only after significant delays, and the gauge locations leave large gaps in coverage. As an alternative, a grid-cell-based formulation for the water requirement satisfaction index (WRSI) was tested for maize in Southern Africa. Grids of input variables were obtained from remote sensing estimates of rainfall, meteorological models, and digital soil maps. The spatial WRSI was computed for the 1996–97 and 1997–98 growing seasons. Maize yields were estimated by regression and compared with a limited number of reports from the field for the 1996–97 season in Zimbabwe. Agreement at a useful level ($r = 0{\cdot}80$) was observed. This is comparable to results from traditional analysis with station data. The findings demonstrate the complementary role that remote sensing, modelling, and geospatial analysis can play in an era when field data collection in sub-Saharan Africa is suffering an unfortunate decline. Published in 2002 by John Wiley & Sons, Ltd.

KEY WORDS crop water; rainfall; remote sensing; Africa; grid

INTRODUCTION

In sub-Saharan Africa, extreme food shortages are most often associated with drought. Rainfall monitoring is therefore an indispensable activity for identification of potential famine areas. However, only a weak relationship has been observed between seasonal station rainfall totals and agricultural yields. The amount and timing of rainfall relative to crop requirements must be considered. This is frequently accomplished with simple, physically based crop water accounting schemes (Frere and Popov, 1986) that can give an indication of crop production months before conventional statistics are available. Even so, station data only tell the story at point locations, and many stations report only after significant delays. Remote sensing estimates of rainfall, data assimilation fields from global circulation models, and digital soil maps make grid-cell-based crop water accounting a viable alternative. Advantages of such an approach stem from results that are spatially continuous and available in near real time.

BACKGROUND

The Famine Early Warning System (FEWS)

Famine is a disaster unlike most others. Whereas earthquakes, tornadoes, or floods strike suddenly and without warning, famine is the culmination of natural and human processes occurring over many months

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(Mellor and Gavian, 1987; Field, 1993). Most of these processes can be observed and documented; if they are, then great human suffering can be avoided.

In the 1970s and early 1980s, sub-Saharan Africa was hit by widespread famine due to prolonged drought and breakdown of human institutions. Food might have been brought in from elsewhere in Africa or from donor countries, but by the time the need had been identified it was no longer logistically possible to deliver food in time to save lives. In response, Congress in 1985 authorized the US Agency for International Development (USAID) to launch the FEWS for sub-Saharan Africa. The FEWS mission statement is 'to provide host country and US decision-makers with timely and accurate information on potential famine areas'.

The Water Requirement Satisfaction Index (WRSI)

Because conventional agricultural production figures are typically unavailable until several months after harvest, simple physically based crop water requirement models have been devised for use with rainfall station data. These models, in turn, permit early estimates of crop yield and production through statistical relationships. The United Nations Food and Agriculture Organization (FAO) has developed the WRSI as an operational model for estimating the agricultural consequences of rainfall in water-limited areas of the world (Frere and Popov, 1986). It is popular with FEWS partners in Africa working at the regional and national level. A brief explanation of the approach follows.

Crop water accounting with the WRSI is done on a dekadal basis using sums of daily rainfall observations from a station representative of conditions in a crop-reporting district. The dekad is the basic 10 day time step of agrometeorological monitoring in Africa. Each month of the year is divided into three dekads: the 1st through the 10th, the 11th through the 20th, and a final dekad of 8, 9, 10, or 11 days. 'Dekad' is a technical term of the World Meteorological Organization (1992). The dekad represents a compromise between a monthly time step, which is inadequate to resolve important crop growth stages, and a daily time step, which imposes a significant data-processing burden without a commensurate gain in agrometeorological information.

Usually the principal staple crop of a region is modelled with the WRSI, though calculations may be made for other crops as well. The calculations require assumption of a soil water holding capacity (WHC) that defines the volume of the conceptual 'bucket' of water available for crop growth. Field data or soil maps may be consulted, but often a somewhat arbitrary value on the order of 50 to 100 mm is adopted. The dekad of planting must also be known. Thereafter, a simple running tally of crop water supply and demand is maintained throughout the cycle of the crop of interest.

Demand is computed from estimates of potential evapotranspiration for a reference crop, modified by a crop coefficient corresponding to the stage of growth of the staple crop of interest. Potential evapotranspiration is computed according to the availability of necessary input data. The Penman–Monteith equation (Shuttleworth, 1992) is the most sophisticated and demanding of input data, requiring air temperature, atmospheric pressure, relative humidity, solar radiation, and wind observations. Inadequate instrumentation often requires use of simpler equations. Long-term climatological averages are also frequently used instead of current year values. Crop coefficients are taken from published technical reports (e.g. Doorenbos and Pruitt, 1977) or are already embedded as options in software developed for calculation of WRSI (Gommes, 1993).

Water supply consists of the dekad's rainfall plus available soil water. If precipitation exceeds the dekad's crop water requirement, it is applied to replenishment of available soil water. If soil water capacity is exceeded, water is lost to the crop as runoff or infiltration beyond the root zone. If crop demand exceeds precipitation in a dekad, soil water is debited to meet the requirement. If the available soil water is not enough to meet the requirement, a crop water deficit is recorded. At the end of the growing season, the WRSI is expressed as the percentage of total crop water requirement satisfied by rainfall or available soil moisture. A value of 100 implies full satisfaction of the requirement, and lesser values indicate the degree of shortfall. A value as low as 40 or 50 implies crop failure.

Mathematically, dekadal updates to seasonal crop water satisfaction (CWS) are calculated as follows:

$$\Delta W_i = R_i + S_i - (K_c E_{rc})_i$$

where ΔW_i (mm) is the moisture deficit or surplus for dekad i, R_i (mm) is the rainfall for dekad i, S_i (mm) is the available soil moisture at the outset of dekad i, K_c (dimensionless) is the crop coefficient for dekad i, and E_{rc} (mm) is the reference crop evapotranspiration for dekad i.

If $\Delta W_i < 0$, there is a crop water deficit for the dekad, and the updated cumulative crop water satisfaction is

$$\text{CWS}_i = \text{CWS}_{i-1} + (K_c E_{rc})_i + \Delta W_i$$

If $\Delta W_i \geq 0$, the updated cumulative crop water satisfaction is

$$\text{CWS}_i = \text{CWS}_{i-1} + (K_c E_{rc})_i$$

Surplus water is assumed to be lost as runoff to streams and rivers or as infiltration beyond the root zone. Available soil moisture is updated by the following simple calculation:

$$S_{i+1} = S_i + R_i - (K_c E_{rc})_i$$

subject to the constraint WHC $\geq S \geq 0$.

WRSI is calculated at the end of the season as:

$$\text{WRSI} = \left[\text{CWS} \Big/ \sum (K_c E_{rc})_i\right] \times 100$$

which is the percentage of the total seasonal crop water requirement satisfied by available rainfall and soil moisture.

Sensitivity to inputs

In order to gain an appreciation for the dependence of the WRSI on input data, a limited sensitivity analysis was undertaken using the FAOINDEX software of Gommes (1993). The case of 120 day maize at Embakasi, Kenya, is an example provided with the computer program and it was used for the analysis. Input variables were systematically varied, one at a time, to gauge the impact on the WRSI relative to the given example. Planting dekad, soil WHC, precipitation, and potential evapotranspiration were each varied. Results showed that systematic over- or under-estimation by 10% of precipitation or potential evapotranspiration resulted in WRSI changes on the order of +/−5% of seasonal crop water requirement. Shifting start of season (SOS) by one dekad earlier or later had a similar effect. Increasing soil WHC by 25 mm and 50 mm had a marked impact, with WRSI increases of 10% and 16% respectively. Table I summarizes the sensitivity analysis results.

Spatial implementation of the WRSI

Recent work by FAO and national early warning services report progress in the area of a spatial solution for the WRSI. For example, Rojas and Amade (1998) developed a map of WRSI values for maize in Mozambique using point solutions for crop reporting districts and inverse distance weighted spatial interpolation. At FAO in Rome, point values of WRSI and associated yield estimates have similarly been interpolated (Gommes and Bernardi, personal communication), though a different algorithm was used. Co-kriging (Bailey and Gatrell, 1995) was applied, with seasonal maximum value normalized difference vegetation index (NDVI) as the covariate used in the interpolation.

The spatial implementation for FEWS differed in two important ways from those cited above. The first is that the WRSI was calculated on a cell by cell basis, using grids of input values corresponding directly to the individual inputs of a point solution (precipitation, potential evapotranspiration, soil WHC, and planting dekad). There was no statistically based spatial interpolation of the WRSI itself; rather, spatial calculation of the input variables preceded calculation of the WRSI. Fields of precipitation and potential evapotranspiration were based on remotely sensed and ground observations and physically based dynamical modelling of the

Table I. Sensitivity of the WRSI for 120 day maize to variations in SOS, WHC, precipitation, and PET

Parameter change (WHC = 50 mm)	WRSI change (base WRSI = 84)
SOS +1 dekad	3
SOS +2 dekad	−8
SOS−1 dekad	−4
WHC +25 mm	10
WHC +50 mm	16
Precipitation +5%	2
Precipitation +10%	4
Precipitation +15%	5
Precipitation −5%	−2
Precipitation −10%	−5
Precipitation −15%	−7
PET +5%	−3
PET +10%	−6
PET +15%	−9
PET −5%	3
PET −10%	6
PET −15%	10

global atmosphere. Soil WHC was derived from digital soil maps, and planting dekad was inferred from the rainfall estimate (RFE) time series. Thereafter, each grid cell was treated exactly the same as a station under the classic method described above. A second important difference was that no use of the NDVI time series was made. This was because an assessment of growing conditions independent of the NDVI data was sought, consistent with the 'convergence of evidence' approach used by FEWS to assess food security.

An initial test of the spatial implementation of the WRSI for FEWS was undertaken in the countries of the Southern Africa Development Community (SADC) owing to the availability of necessary data and the active interest of scientists in the region.

DATA USED IN GRID CELL CROP WATER ACCOUNTING

Gridded rainfall data

Two operational remote sensing products are used by FEWS to monitor agricultural areas on a near real-time, spatially continuous basis for signs of drought. They are NDVI images from the National Aeronautics and Space Administration's Goddard Space Flight Center (Los *et al.*, 1994) and RFE images (Herman *et al.*, 1997) prepared by the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA). Both are compiled on a dekadal time step.

Grid cell crop water accounting for FEWS was implemented on the 0·1° grid of the RFE. The RFEs are produced operationally by NOAA from thermal infrared images from Meteosat, acquired every 30 min, that identify areas of cold cloud top temperatures (less than 235 K). The duration of these temperatures over a day is used to make an initial estimate of convective rainfall. Then, daily rainfall totals from 760 stations that report electronically through the WMO Global Telecommunication System (GTS) are used to remove bias from the cold cloud estimates. Finally, areas of 'warm cloud' rainfall, associated with orography, coastal areas, and frontal activity, are estimated from output fields of NOAA's operational weather forecast model, the Global Data Assimilation System (GDAS) (Kanamitsu, 1989). Fields of wind, relative humidity, and a digital elevation model are used to identify these areas of non-convective lifting and condensation. Figure 1 displays an example RFE product.

Herman *et al*. (1997) compared RFEs with independent station data for 180 rain gauges in Mali, Niger and Chad for the dekads of June through September 1995. Their analysis revealed a correlation coefficient of 0·86 for 1780 observations (some stations had missing data for certain dekads). Rojas and Amade (1998) compared dekadal RFEs with station values for 60 gauges in Mozambique over a 3 month period, December 1997 through February 1998. They computed correlations for each station and found values in the range of 0·65 to 0·80, or better, for stations representing about three-quarters of the country. Pockets of weaker correlations, mostly in the range of 0·45 to 0·65, accounted for the rest of the area. A tendency for underestimation was observed.

To assess the reliability of the RFE in the SADC region, we computed spatial cross-correlations with grids of monthly long-term average rainfall provided by the Agrometeorology Group of FAO in Rome (M. Bernardi, personal communication). FAO prepared these grids by fitting surfaces to station data from the FAOCLIM agroclimatic database (FAO, 1997). The months of December through March of the 1996–97 and 1997–98 growing seasons were examined. Correlations varied between 0·58 and 0·82, as shown in Table II. These values, along with visual examination, gave confidence that the spatial patterns of the RFE are consistent with those to be expected from climatology.

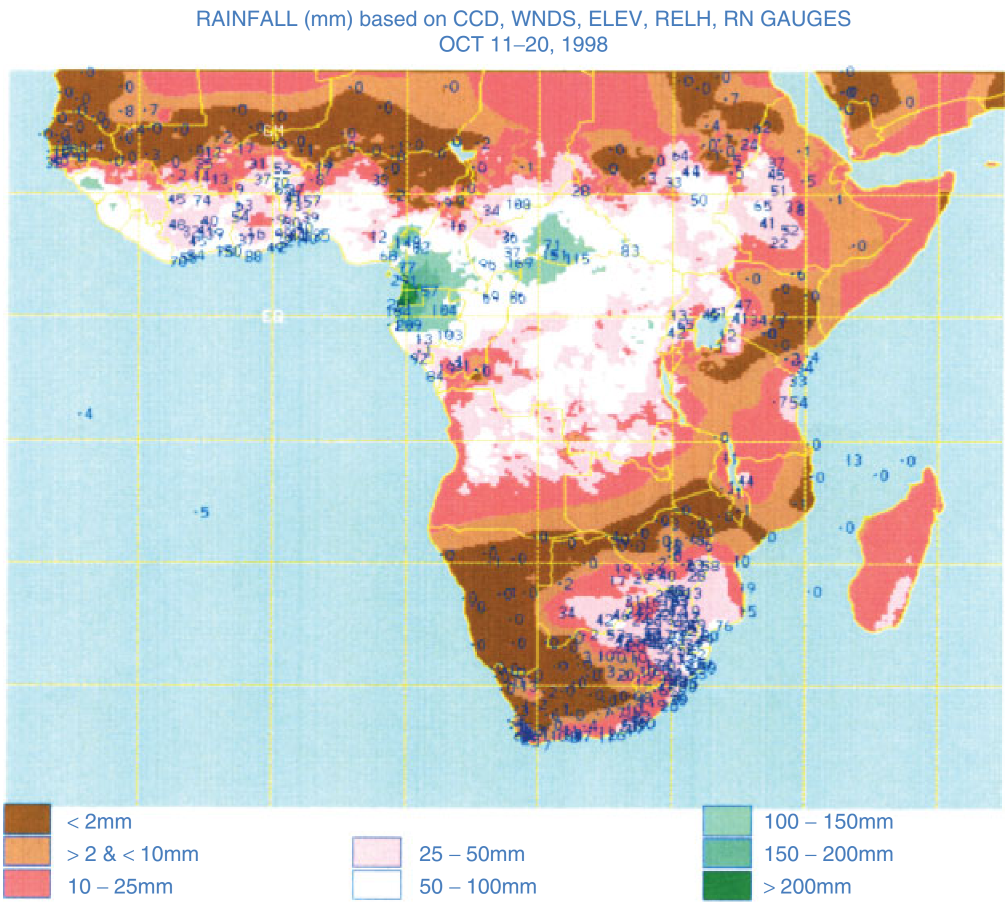

Figure 1. An example RFE image from NOAA's Climate Prediction Center

Table II. Cross-correlation values computed between long-term average SADC region precipitation grids from FAO and RFE grids for months of the 1996–97 and 1997–98 Southern Africa maize-growing seasons

RFE	FAO	*r*
Dec 96	Dec avg	0·74
Jan 97	Jan avg	0·73
Feb 97	Feb avg	0·82
Mar 97	Mar avg	0·58
Dec 97	Dec avg	0·72
Jan 98	Jan avg	0·78
Feb 98	Feb avg	0·75
Mar 98	Mar avg	0·72

Gridded evapotranspiration data

GDAS analysis fields, generated every 6 h, were used to estimate dekadal potential evapotranspiration on a spatial basis using the Penman–Monteith equation for reference crop evapotranspiration (Shuttleworth, 1992). The spatial resolution of the fields was 1°, or about 100 km. Fields used include air temperature, atmospheric pressure at the surface, wind, relative humidity, and radiation (long wave and short wave, outgoing and incoming). Each day's potential evapotranspiration was computed, and appropriate sums made to get dekadal totals for the WRSI.

In order to assess the validity of the potential evapotranspiration (PET) estimates for 1996–97 and 1997–98 in Southern Africa, they were compared with long-term average values on both a point and a spatial basis. P. Mattei (personal communication) provided files of dekadal values for 243 stations from throughout the SADC region. These same data were used to make the WRSI calculations reported in Mattei and Sakamoto (1993). The PET values for the 1997–98 growing season were extracted from the grids at the station locations, and a correlation of 0·77 was calculated. Figure 2 presents a scatter plot of the data pairs. Grids of monthly long-term average PET (M. Bernardi, personal communication) were also quantitatively compared with the FEWS spatial estimates by computing spatial cross-correlations. Values varied between 0·38 and 0·82, as shown in Table III. It should be noted that values for December 1996 and January 1997 pre-date the availability to the project of 1·0° GDAS fields, and they were instead computed with 2·5° GDAS fields from the NOAA archive. If these coarser-resolution data are excluded, the minimum cross-correlation value increases from 0·38 to 0·66. Though concurrent station values of PET would be preferred for evaluation of the grids of PET, such data are difficult to obtain. The comparisons that we have been able to make with climatological values do not discourage calculation of PET from GDAS grids.

Gridded soils data

The spatial variation of soil WHC was characterized using the FAO digital soil map of the world (FAO, 1994). The scale of the original mapping was 1 : 5 000 000, and the soil polygons carried attributes that included an estimate of easily available water capacity in the upper 100 cm, based on soil physical characteristics. These are the values adopted as WHC for the spatial calculation of the WRSI. The soil map was rasterized to match the 0·1° RFE grid.

Comparisons of these WHC values were made with those used at the stations of Mattei and Sakamoto (1993). A scatter plot of values for the two data sets is displayed in Figure 3. It can be seen that the range of values is similar; however, there is not much agreement from point to point. Note that the distribution of

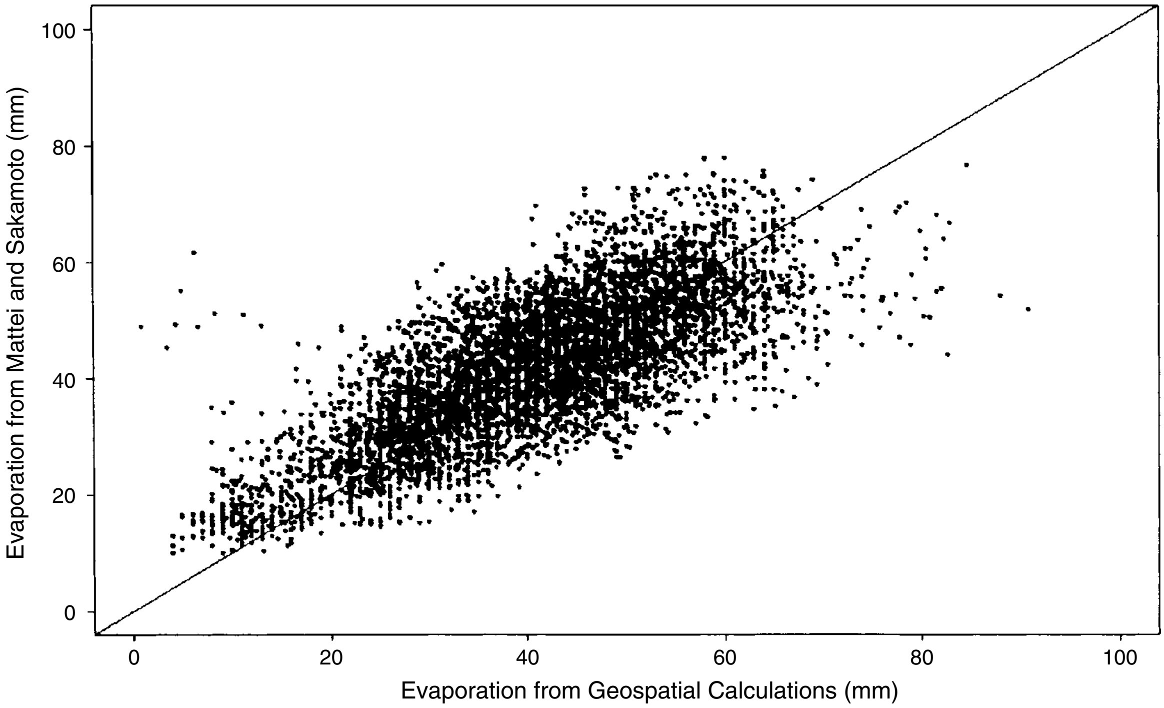

Figure 2. Scatter plot of long-term average dekadal PET versus 1997–98 FEWS geospatial estimates from GDAS analysis fields for the 243 station locations of Mattei and Sakamoto (1993). The pattern illustrates the 0·77 correlation between the two data sets

Table III. Cross-correlation values computed between long-term average SADC region PET grids from FAO and GDAS-computed grids for months of the 1996–97 and 1997–98 Southern Africa maize-growing seasons

FEWS	FAO	*r*
Dec-96	Dec avg	0·46
Jan-97	Jan avg	0·38
Feb-97	Feb avg	0·74
Mar-97	Mar avg	0·82
Dec-97	Dec avg	0·74
Jan-98	Jan avg	0·74
Feb-98	Feb avg	0·66
Mar-98	Mar avg	0·77

values is more continuous in the case of the FAO digital soil map of Africa. We interpret this plot to mean that the assignment of WHC values according to the soil map is less arbitrary and more physically based than those adopted by Mattei and Sakamoto.

Crop coefficients

Crop coefficients, needed to modify PET in each dekad according to crop phenology, can be obtained from the FAOINDEX software (Gommes, 1993) or other suitable reference (e.g. Doorenbos and Pruitt, 1977). We

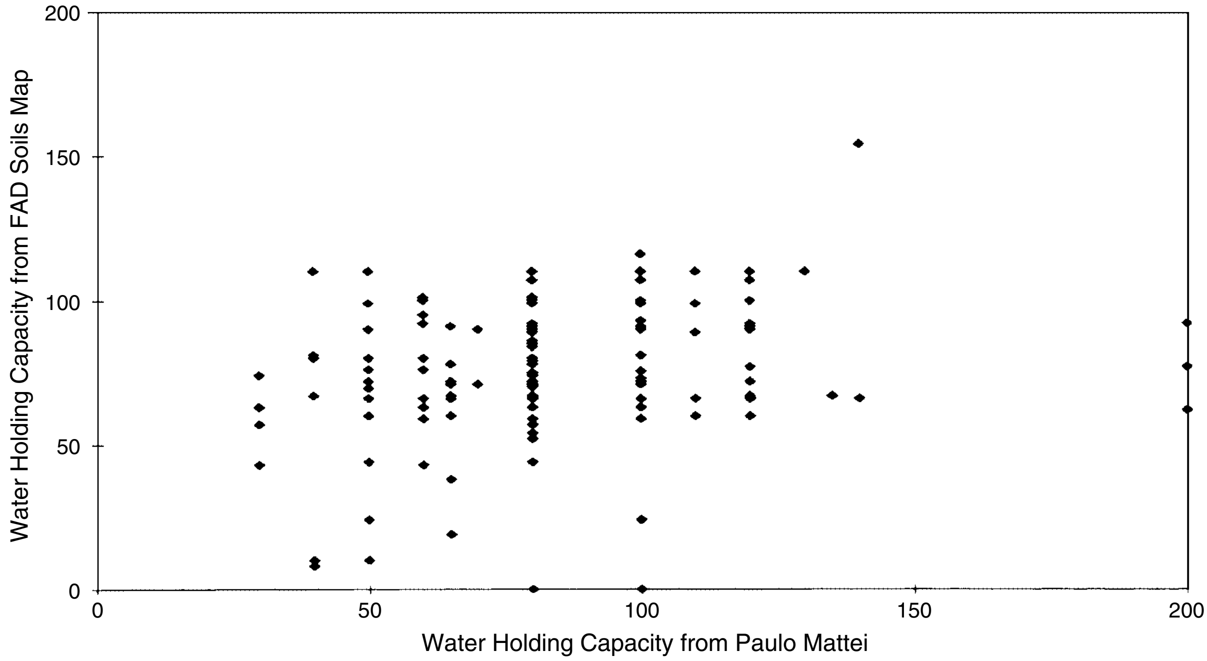

Figure 3. Distributions of WHC values for the 243 stations from Mattei and Sakamoto (1993) and the FAO digital soil map of the world at the same locations

adopted FAOINDEX values for 120 day maize, the most widespread staple in the SADC region, for all grid cells of the spatial implementation of the WRSI.

METHODS USED IN GRID CELL CROP WATER ACCOUNTING

Estimating planting dekad and calculating the WRSI

The planting, or SOS, dekad was identified by processing the RFE time series for the growing season. On a per pixel basis, rainfall criteria developed at the Agriculture–Hydrology–Meteorology (AGRHYMET) Regional Center in Niger (AGRHYMET, 1996) were applied to the RFE values. Beginning several dekads in advance of the usual SOS, each pixel was tested to identify the first dekad in which at least 25 mm of rain fell. To test for failed plantings, the next two dekads' rainfall had to total to at least 20 mm. If not, testing for the planting dekad continued.

Once the SOS dekad was determined for each grid cell, the WRSI calculations were made using a program written in the Arc Macro Language (Klaver *et al.*, 1997) for use with the ARC/INFO GRID software. In this code, each grid cell is treated exactly the same as a station in the traditional FAO method. The WRSI was calculated in this way for the SADC countries for the 1996–97 and 1997–98 seasons.

Relating WRSI to maize yield

Typically, the proportionality between the WRSI and reported crop yields is used to develop local regressions for estimation of crop yield having WRSI as the independent variable. Coefficients of determination (r^2) on the order of 0·75, are commonly reported (Frere and Popov, 1986; Mattei and Sakamoto, 1993; Rojas, 1994; Gommes *et al.*, 1996). Both linear and exponential models have been used. These regression models of yield, along with field observations of planted area, are used to make estimates of crop production immediately at harvest, months before conventional figures become available.

There are great differences in climate and soils from place to place over a large region like Southern Africa. For this reason it has usually proven necessary to normalize yield data relative to a long-term local average or historical maximum for purposes of a developing regression model.

Development of useful regressions requires a large number of observations from widespread locations over several years, with a good range of both wet and dry conditions represented. Owing to the limited availability of yield data and the short period of record for the gridded inputs (RFE, GDAS 1° fields), we were unable to develop regressions directly using grid cell data. Instead, we elected to use an existing regression estimator based on station calculations of WRSI. It was an SADC-wide estimator developed by Mattei and Sakamoto (1993). It is of the form:

$$Y = 3{\cdot}58\mathrm{WRSI}_{\mathrm{avg}} - 258{\cdot}6$$

where Y is yield as a percentage of the district historical average yield (kg ha^{-1}) and $\mathrm{WRSI}_{\mathrm{avg}}$ is current period WRSI expressed as a percentage of the district historical average WRSI. Their estimator was developed using data from 206 points. They reported a coefficient of determination of 0·74, a correlation coefficient of 0·86, and a standard error of estimate of 26·6 kg ha^{-1}.

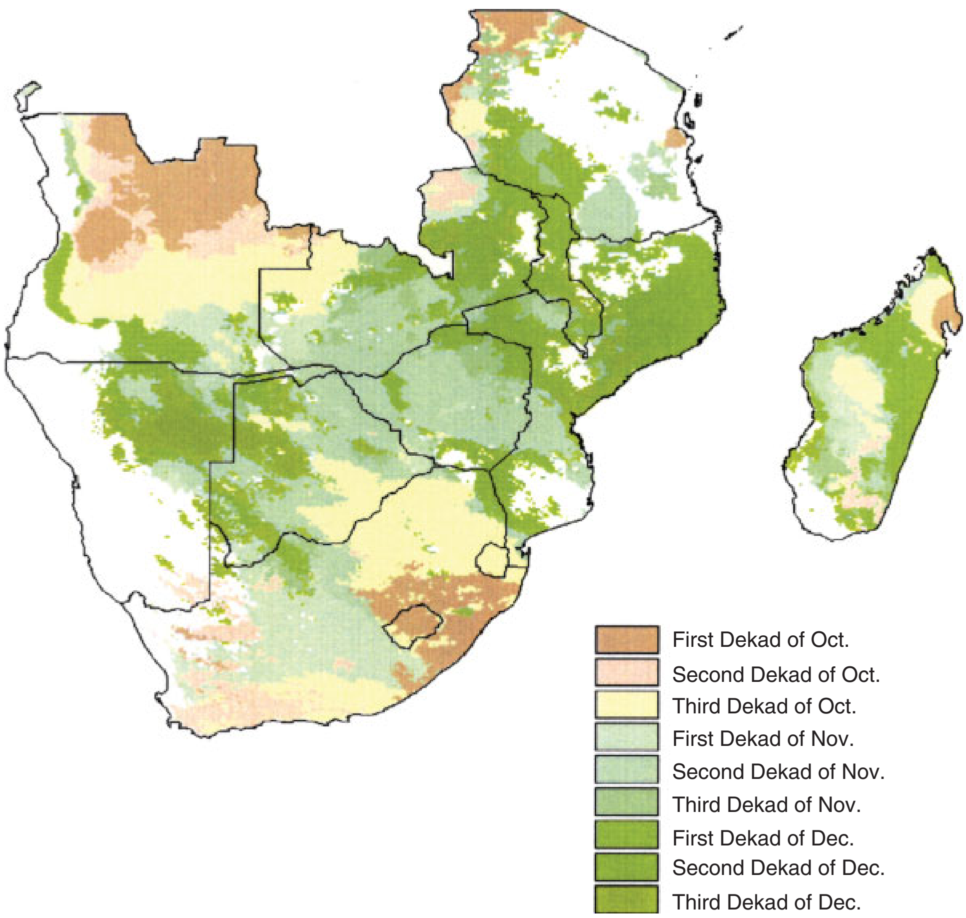

Figure 4. SOS determination through application of AGRHYMET criteria to the RFE time series for the 1996–97 season for the SADC countries

RESULTS

SOS results for the SADC region

Grid cell SOS estimates were obtained for the 1996–97 and 1997–98 growing seasons in the SADC countries. Figure 4 illustrates the estimates for the 1996–97 season. It was possible to evaluate the 1997–98 results by comparing them with reports from the field for maize in Mozambique (O. Rojas, personal communication). Since these reports were compiled on a district basis, the per-pixel values were aggregated by taking the median pixel value within each district. The results of the comparison are presented in two forms. Figure 5 presents side-by-side colour-coded district maps of Mozambique, and Table IV presents a confusion matrix. In Table IV, instances of agreement between RFEs of SOS and field reports are tallied along the diagonal. Off the diagonal are cases of disagreement. The results are positive by both measures, which is encouraging in view of the fact that the criteria were originally developed in West Africa rather than Southern Africa.

WRSI results for the SADC region

The WRSI output grids are presented in Figure 6. The observed patterns generally reflect the favourable conditions that prevail in the traditional maize-growing regions of the SADC countries. However, it is interesting to observe interannual differences that are evident. In April 1997, it was announced that the government of Tanzania would release 10 000 t of maize from its strategic grain reserves to cope with drought-related food shortages (FEWS Project, 1997). By contrast, in June, 1998, above-average production and dropping food prices were reported in that country (FEWS Project, 1998). The WRSI patterns for Tanzania in Figure 6 are consistent with these reports. In the maize-growing region of northeastern Namibia, the opposite sequence was observed. A good harvest was had in 1997, but significant drought impacts were suffered in 1998. Again, the WRSI patterns in Figure 6 are consistent with field reports.

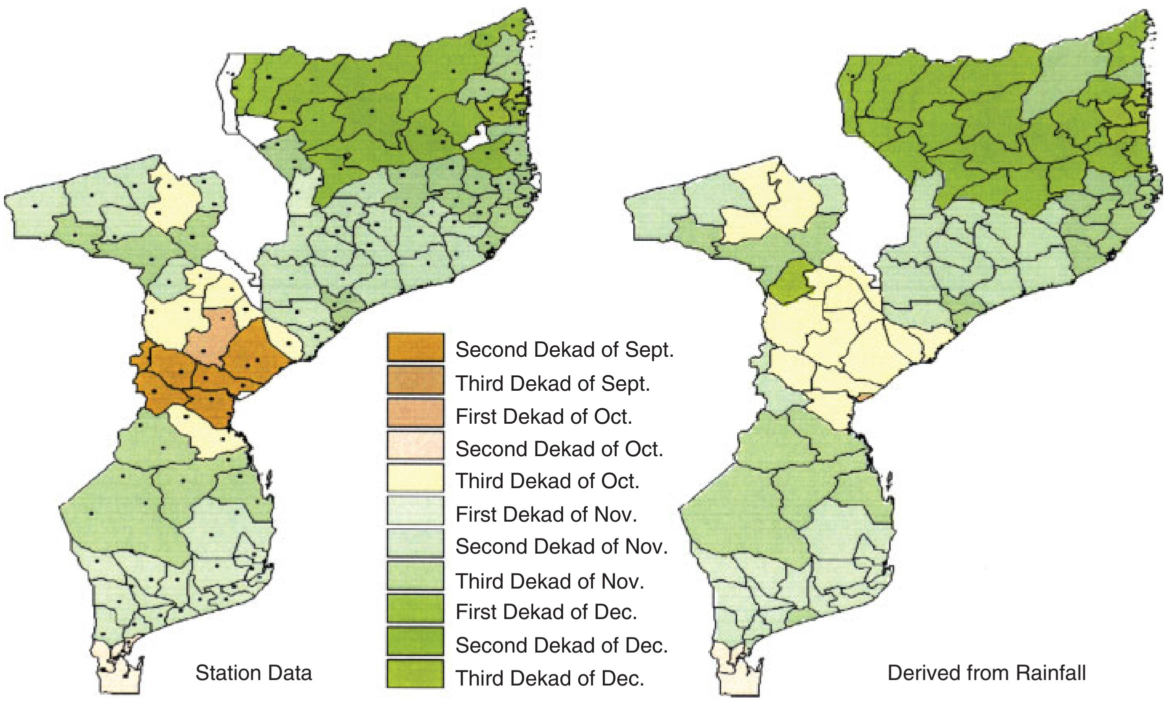

Figure 5. SOS by district for 1997–98 in Mozambique, as reported from the field (left) and as estimated from the RFE time series (right)

Table IV. Confusion matrix for comparison of SOS estimates, based on analysis of RFE, with reports from districts in Mozambique for the 1997–98 growing season

Reported SOS	SOS calculated from RFE								
	29	30	31	32	33	34	35	36	Total
26	0	3	0	2	0	0	0	0	5
28	0	1	0	0	0	0	0	0	1
29	**3**	0	0	1	0	0	0	0	4
30	0	**6**	0	0	1	0	0	0	7
31	0	0	**0**	1	0	0	0	0	1
32	0	3	0	**32**	3	1	0	1	40
33	0	0	0	0	**17**	4	2	1	24
34	0	0	0	0	0	**5**	2	0	7
35	0	0	0	0	0	0	**5**	1	6
36	0	0	0	0	0	0	0	**2**	2
Total	3	13	0	36	21	10	9	5	97

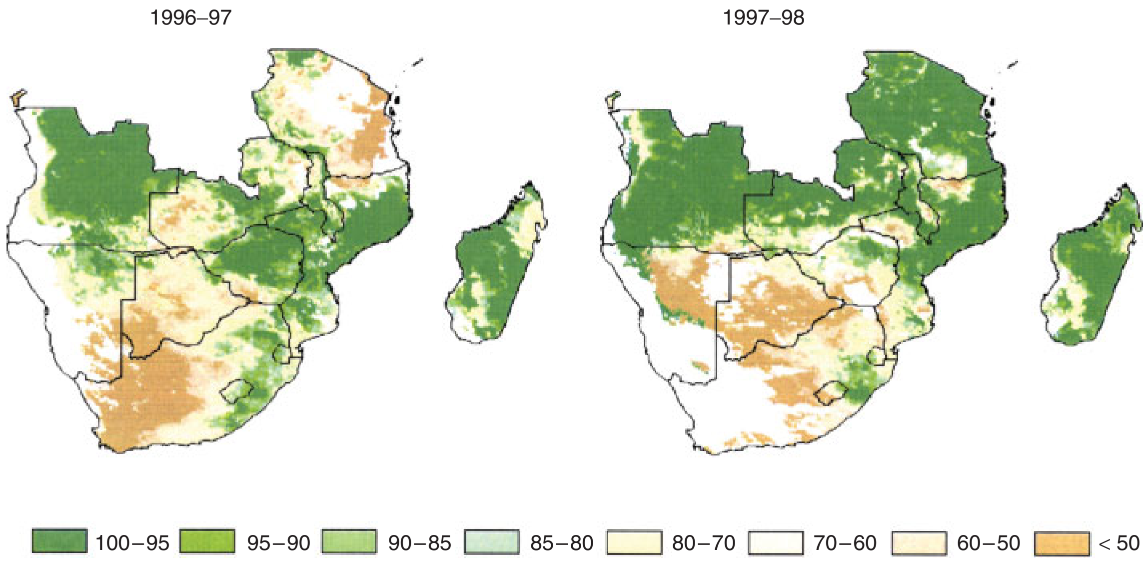

Figure 6. WRSI for the 1996–97 and 1997–98 growing seasons in the SADC countries

Comparison of yield estimates with reports from the field

Figure 7 presents a map of maize yield for the 1996–97 growing season obtained by application of the SADC-wide maize yield estimator of Mattei and Sakamoto (1993) to the WRSI map of Figure 6. In order to test the maize yield estimates derived from the spatial WRSI, it was possible to obtain a limited number of Zimbabwean maize yield reports for the 1996–97 growing season. These figures were compiled on a communal land basis, the fifth level administrative unit of that country. Figure 8 is a scatter plot of estimated versus reported maize yield for 14 communal lands, and illustrates the correlation of 0·80 that was computed between the two sets of figures.

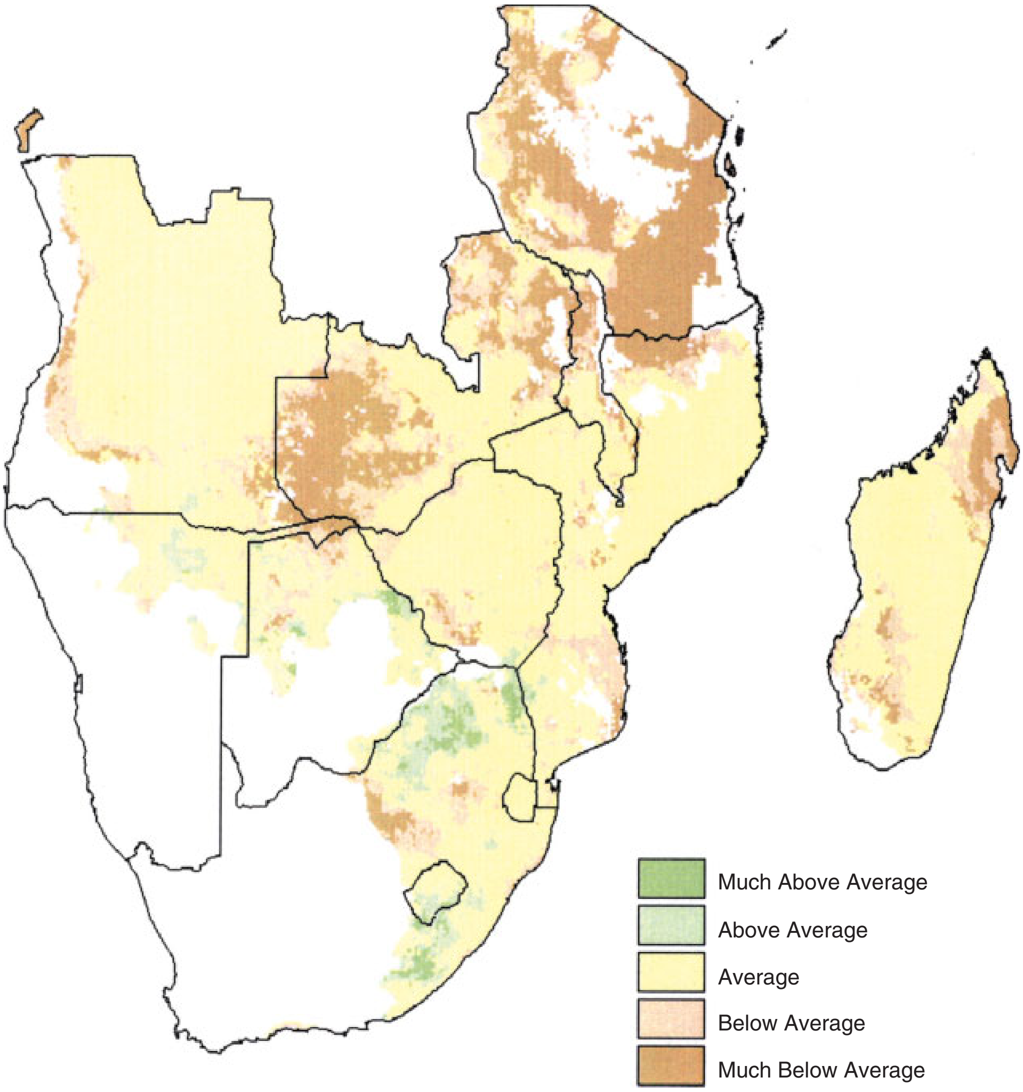

Figure 7. Maize yield map for the SADC countries for the 1996–97 growing season

DISCUSSION AND CONCLUSIONS

It is important to assess the quality of the harvest of staple crops as early as possible, in order to plan for the year ahead. If a hungry period is to be experienced, it will occur in the latter half of the coming year, when stocks from the present harvest run low, prices rise, and the next year's crop is still in the field. Necessary measures might consist of market interventions, food for work programs, or direct food aid. If food aid will be needed, early warning can come none too soon because 'the time needed to get food to famine-stricken areas after an appeal for aid can stretch to six months or more' (Ulrich, 1993).

Crop production reports compiled by conventional methods of agricultural statistics are only available several months after harvest. FAO developed the WRSI and yield regressions to provide early warning of potential food security problems so that action can be taken even while conventional figures are still being

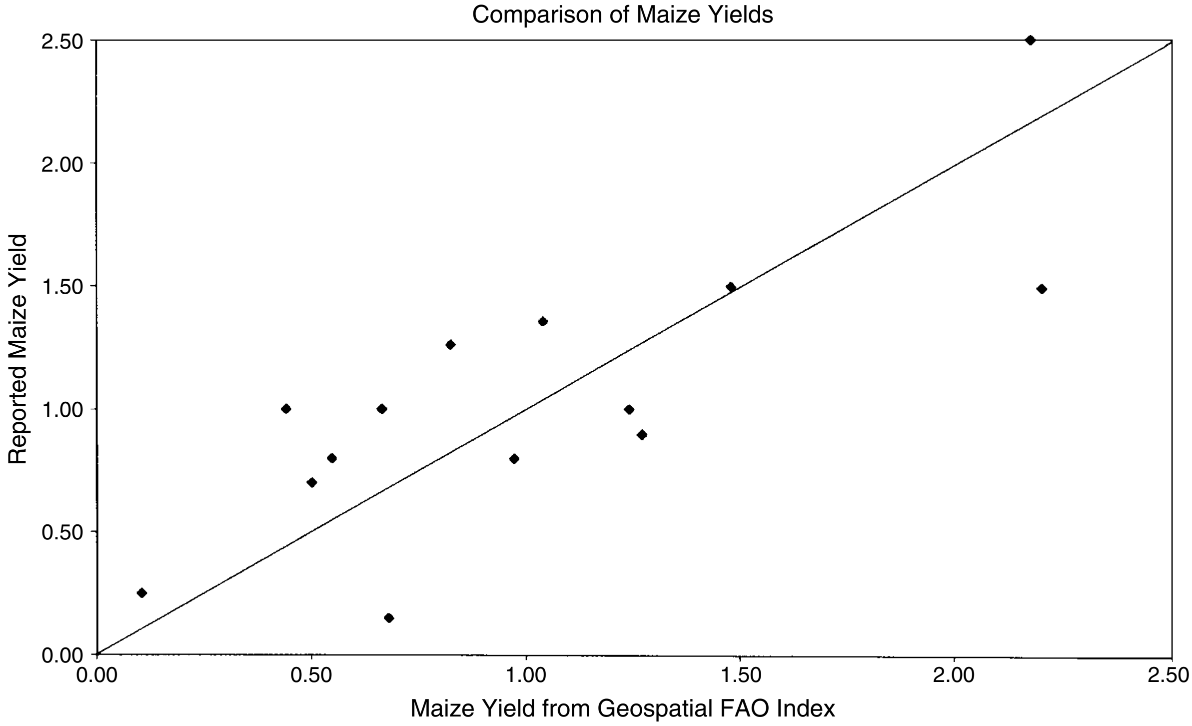

Figure 8. Scatter plot of estimated versus reported 1996–97 maize yields for 14 communal lands of Zimbabwe

prepared. (In some countries, estimates of this kind are the *only* available figures.) Nonetheless, the traditional use of the WRSI is limited to rainfall stations reporting in a timely manner, leaving wide areas without information.

As a complement to traditional methods, we have demonstrated a version of the WRSI that uses grids of input data to compute the index on a spatially continuous basis. The technique was applied to the entire SADC region for two growing seasons. Limited field reports of yield were available from Zimbabwe for one season, 1996–97, for validation. Comparison of these field reports with grid cell estimates showed good agreement, with a linear correlation of 0·80. Because the necessary input data are produced operationally in electronic form and are available in near real time, the spatial implementation of the WRSI can likewise be applied in near real time. With appropriate internet connectivity, the technique can be applied in Africa, where local knowledge of agricultural practices can be used to refine parameters, like SOS and crop coefficient values, to improve estimates.

In a period of reduced field data collection by African governments due to financial hardship, these are important results. Food security analysts can be provided with valuable information on current conditions in areas without ground data through the integrated use of remote sensing, atmospheric modelling, and geospatial data analysis. Positive initial results and the ongoing need for food security information strongly encourage further implementation and testing of grid-cell-based crop water accounting.

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