Validation of Crop Weather Models for Crop Assessment and Yield Prediction under Tanzania Conditions

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Abstract

Information gathering for early warning and crop assessment in Tanzania is based on physical inspection of standing crop in sample fields. This process is subject to human error, inadequate and is also time consuming. Recent developments in computer simulation have paved the way for more efficient methods of analysing data for purposes of early warning and crop assessment. Two such schemes based on soil water balance simulation, viz. IRSIS and CRPSM models were used in this study to see how closely they could predict grain yields for selected stations in Tanzania. Input for the models comprised of weather, crop and soil data collected from five selected stations. Simulation results show that IRSIS model tends to overpredict grain yields of maize, sorghum and wheat, a fact that could be attributed to the inadequacy of the model to accurately account for rainfall excess. On the other hand, the CRPSM model simulated results were not significantly different (P>0.05) from the actual grain yields of maize, sorghum, wheat and beans. Although the agreement between actual and simulated yield data was good, it was observed that mean values for predicted grain yields were consistently lower than for actual grain yields. This could be attributed to the use of approximate rather than location specific input parameters required by the CRPSM model. Locally calibrated input parameters in the CRPSM model could further improve the accuracy of the model and hence its ability to predict grain yields.

Keywords: Soil water balance, simulation model, crop assessment, yield prediction

Introduction

Early warning schemes and related crop yield forecasting methods aim at predicting a possible crop failure as early as possible in the course of the growing season. This allows the producers to estimate in advance the size of the harvest and the portion of it which can be sold or exported (Snijders, 1986). Conversely, early warning schemes are equally important for the food-deficit regions in order to predict in advance the size of the national harvest, their export capacity and the portion of the country's food consumption which has to be procured from elsewhere. For such prediction, the inspection of the standing crop (sown area, state of development, infestation by pests and diseases etc.) in the region under consideration is a natural means.

Recent developments in computer models for predicting crop yields as influenced by weather, crop characteristics and soil physical properties have a potential to provide more reliable results. Crop weather models like the irrigation scheduling information system (IRSIS) (Raes *et al.*, 1988) and crop yield and soil water management simulation model (CRPSM) (Hill *et al.*, 1987; Hill, 1997) are two such models. These models fall under the category of statistically based

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crop-weather analysis models as proposed by Baier (1979).

The primary objective of a crop-weather analysis model is to analyse the daily contributions of up to three selected agrometeorological variables to the final or seasonal yield (Baier, 1979, 1981). The crop response to each of the three input variables is either linear (positive or negative) or quadratic (concave or convex). The response changes gradually during the life cycle of annual crops as a function of biometeorological time (Robertson, 1968). The decision regarding the functional relationship to be used in the model is based on the assumption that crop yield depends basically on three agrometeorological variables: solar energy, temperature and soil moisture. These three variables modify each other on any particular day during the life cycle of a crop and produce a positive or negative effect on the final yield.

Of particular interest in this category is the crop forecasting method based on agrometeorological information defined by the Crop Ecology and Genetic Resource Unit of the Plant Production and Protection Division of FAO (Frère and Popov, 1979). The method is based on cumulative water balance established over the entire growing season for a given crop for successive periods of 10 days (or 7 days if preferred). The extent to which the water requirements of an annual crop have been satisfied in a cumulative way at any stage of its growing period is expressed as an index which is directly related to yield and can at least give a very satisfactory and early qualitative appreciation of the yield (Frère and Popov, 1979).

It is also possible to derive quantitative estimates of yields, but these estimates have to be based on the potential yield of crops, which will depend on the local environmental conditions and will vary from place to place. In this way the establishment of precise correlation linking index and actual yields will only be possible when precise agricultural yield statistics are available for given regions. While the method allows good qualitative assessments, the quantitative forecast will always depend on good historical statistics of yield and production (Frère and Popov, 1979).

Other workers (e.g. De Wit, 1958; Bielorai *et al.*, 1964; Hanks *et al.*, 1969; Stewart et al., 1975; and Stewart *et al.*, 1977) have reported a strong linear relationship between yield of various crops and either seasonal evapotranspiration (ET) or total transpiration (T). Models which are based on the assumption that crop yield is directly related to ET are somewhat site and year specific and require measurements or estimates of ET and maximum yield. A major deficiency with such models relates to the amount of soil evaporation, E, which varies from year to year and from site to site (Hanks and Hillel, 1980). IRSIS model belongs to this category.

Transpiration models on the other hand are based on the strong linear relation of transpiration with yield (Briggs and Shantz, 1913; De Wit., 1958; Jensen, 1968; and Hanks, 1974). These models eliminate the problems mentioned previously and are more readily transferable both in space and time. They are more sound than those relating to ET because they account for the water that goes through the plant even though it is difficult to separate the two processes (Hanks and Hill, 1980). CRPSM model belongs to this category.

Use of crop yield models for predicting yields has a significant bearing on the food security of many people in the region. Unfortunately such models have not yet undergone rigorous testing under the prevailing conditions. The aim of the current study was therefore to validate two of the commonly used soil water balance simulation models for crop assessment and crop yield prediction under Tanzanian conditions.

Materials and Methods

Data

Five stations were selected from two regions in the country viz. Morogoro and Arusha. For Morogoro region, the stations were Ilonga Agricultural Research and Training Centre (IARTC) and Msimba Foundation Seed Farm (MFSF). Those in Arusha region were Selian Agricultural Research Institute (SARI), Arusha Foundation Seed Farm (AFSF) and Tanzania Pesticides Research Institute (TPRI). The criterion used to select these stations was the availability of sufficient data to undertake the study.

Pertinent data on weather, crop and soil were collected from the respective stations spanning some ten years. These included daily rainfall, radiation, temperature, relative humidity and wind speed for weather data; actual and potential yield for crop data; and soil type, available soil water and basic infiltration rate for soil data. The crops studied included maize, wheat, sorghum and beans.

Description of computer programmes

Two crop weather models viz. CRPSM and IRSIS models were adopted for this study. These have been described by Hill *et al.*(1987), Hill (1997) and Raes *et al.* (1988). Input data for both models include weather, crop and soil data. The output from the CRPSM model includes the reference crop evapotranspiration, potential and actual transpiration, potential and actual evaporation, seasonal soil water budget and the predicted grain yields. On the other hand, the output from the IRSIS model comprises of soil water balance, root zone depletion, simulated yields and rainfall application efficiency. Only yield data simulated at the maturity stage were used for subsequent analyses. Irrigation data were not considered, thus the root zone was assumed to have gained water through rainfall only.

Three different planting dates for each year and each type of crop and variety were used to simulate crop yields, i.e. actual planting dates; three days after the actual planting dates and planting dates as determined by Kassasse (1992) for Morogoro and Arusha. Each of the crop yield results simulated by both IRSIS and CRPSM models were statistically compared with the actual crop yield data obtained from the fields using the t-Test.

Results and Discussion

Comparison of observed with model predicted grain yield

Tables 1 and 2 show figures of yield for maize (Staha variety) for Ilonga and Msimba stations and wheat (Mbayuwayu and Mbuni varieties combined) for Selian and Arusha Foundation Seed Farm stations respectively as derived from the respective models and from field records. There was no significant difference ($P > 0.05$) between yield data derived from CRPSM model for all possible planting dates and actual yield. Similar results were obtained from the other varieties of maize (Kito and TMV-1) and sorghum (Tegemeo) as well as for the Arusha stations in the case of wheat (Mbayuwayu and Mbuni varieties) and beans (Lyamungu 85 and Lyamungu 90 varieties). These results compare favourably with those obtained by Hill *et al.* (1987).

On estimating the crop yield, the CRPSM model assumes that the only process influencing plant yield directly is the ratio of transpiration (T) to potential transpiration (T_P). Generally, the observed results attest the assumption because they do agree with the observations made by Briggs and Shantz (1913), De Wit 1958), Jensen (1968), Hanks (1974) and others that, models relating yield to transpiration are more sound than those relating yield to evapotranspiration because they account for water that goes through the plant.

On the other hand the agreement between actual and IRSIS simulated maize yield for Morogoro stations was not so good save for planting dates falling on or after the probable date for start of the growing season as determined by Kassase (1992). The disagreement between actual and simulated yield was also significant ($P > 0.05$) for the case of wheat (Arusha stations) but not for beans. However the latter result can not be relied upon as the sample size ($n = 3$) for beans yield data was too small.

These results further attest to what was observed by Hanks and Hill (1980) that, a major problem with ET models which relate the crop yield to ET by linear regression lies in the E part of ET, which varies from year to year, and from site to site. IRSIS model uses the ET model as a subroutine for estimating crop yield.

Another factor that could contribute to the inaccuracy inherent in IRSIS model is the failure of the model to deal with rainfall excess in a manner that is satisfactory. For instance, in Fig. 1 which is a graphical display of root zone depletion for the case of maize (Staha variety), it can be noted that, the depletion of soil water by the crop takes place even for water which is above the field capacity that may be considered as runoff or deep percolation. This is a major weakness of the IRSIS model.

Raes *et al.* (1988) observed that the runoff calculated using the SCS - Curve Number (CN) method might give a poor estimate because factors such as the hill slope and rain intensity are

Table 1: Yield data (kg/ha) analysis for maize (variety:Staha) for Ilonga and Msimba stations, Morogoro

Year	Actual yield	CRPSM Predicted yields for respective planting date*				IRSIS Predicted yeilds for respective planting dates *			
	Y_a	Y_1	Y_3	Y_{GSs}	Y_{avg}**	Y_1	Y_3	Y_{avg}	Y_{avg}**
1989	1864	1800	1780	1510	1697	2352	2400	2400	2384
1990	1504	1670	1610	1080	1453	2160	2016	1368	1848
1991	1400	1470	1420	1170	1353	2057	2107	1512	1892
1992	1585	1860	1760	1390	1670	2400	2400	2184	2328
1993	895	1020	940	870	943	1454	1394	1340	1396
1994	895	1590	1510	960	1353	2230	1505	1416	1717
1995	1440	1580	1560	1210	1450	2304	2256	1488	2048
1996	1470	1710	1630	1460	1600	2400	2400	2400	2400

T-Test (Comparison of two samples)

	Y_1 vs Y_a	Y_3 vs Y_a	YGSs^{VS} Ya Y_a	Y_{avg} ^{VS} Y_a	Y_1 ^{VS} Y_a	Y_3 ^{VS} Y_a	YGSs^{Vs} Y_a	Yavg^{Vs} Y_a
Significance	NS	NS	NS	NS	S	S	NS	S

* Simulated yield for: Actual planting date (Y_1), planting date three days later (Y_3), and planting date failling on or after the most probablem date for start of the growing season (Y_{GSs})

**	Average of Y_1, Y_3 and Y_{GSs}
NS	Not signifacant at $P > 0.05$
S	Significant at $P < 0.05$
Gss	Start of the growing season

Table 2: Yield data (kg/ha) analysis for wheat (varieties: Mbayuwayu and Mbuni comoned) for Selian and Arusha Foundation Seed Farm stations, Arusha

	SRPSM					IRSIS			
Year	Actual yield	Predicted yields for respective planting dates*				Predicted yeilds for respective planting dates*			
	Y_a	Y_1	Y_3	Y_{GSs}	Y_{avg}**	Y_1	Y_3	Y_{avg}	Y_{avg}**
1987	1022	1320	1110	970	1133	1920	1959	1962	1957
1988	1642	1220	1240	1270	1243	1587	1566	1557	1570
1989	1846	1150	1110	1080	1113	1740	1683	1644	1689
1990	1051	1510	1250	1070	1277	2622	2460	2331	2471
1991	1752	1850	1750	1700	1767	3000	3000	3000	3000
1992	1946	2080	1920	1770	1923	3000	3000	2991	2997
1993	1129	1000	910	710	873	1569	1563	1548	1560
1994	1859	1840	1090	1090	1433	1683	1647	1626	1652
1995	1350	1490	1050	1050	1260	1770	1746	1716	1744

t- test (Comparison of two samples)

	Y_1 VS Y_a	Y_3 VS Y_a	Y_{GSs} VS Y_a	Y_{avg} VS Y_a	Y1 VS Ya	Y_3 VS Ya	YGSs VS Y_a	Y_{avg} VS Y_a
Significance	NS	NS	NS	NS	S	S	S	S

* Simulated yields for: Actual planting date (Y1), planting date three days later (Y3), and planting date falling on or after the most probable date for start of the frowing seasn (YGSs)

** Average of Y_1, Y_3 and Y_{GSs})

NS Not significant at $P > 0.05$

S Significant at $P < 0.05$

Gss Start of the growing season

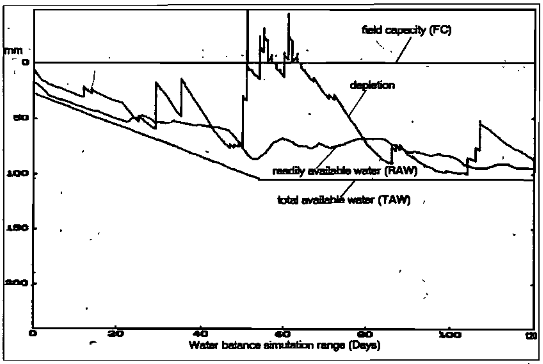

Figure 1: Root zone depletion graph for maize (staha) for 1991 season (IRSIS) graphical display)

not taken into account. IRSIS uses the CN method in the runoff subroutine. It should be noted that the CN method is applicable to larger basins up to several thousand hectares (Smedema and Rycroft, 1983). In contrast, fields from where data were collected for this study do not measure to such size. The CRPSM model however assumes that irrigation and/or rain water infiltrate instantaneously, that is, the surface runoff is not accounted for by the model. But the model assumes instantaneous drainage of excess soil water. In this way excess water is catered for and is not made available to the crop.
The foregoing clearly indicates that IRSIS model considers part of the excess rainfall as water that is available to the crop. This shows to some extent why the model over-estimates the crop yields. It further indicates that IRSIS model is not sensitive to water logging whereas CRPSM model uses a simple function to reduce yields as a result of excessive water.

The usefulness of the models could be enhanced if climate forecast information is readily available. IRSIS has provision for input of such data. However present day forecasting techniques have not yet achieved the required refinement

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References

Baier, W. 1979. Note on the terminology of crop-water models. Agric. Meteorology 20: 137 - 45.

Baier, W. 1981. Agroclimatic modelling: An overview. In: D.F. Cusack (Eds.),Agroclimatic information for development. Westview Press/Boulder, Colorado pp 57 - 87.

Bielorai, H., Arnon, I., Blum, A., Elkana, Y. and Reiss, A. 1964. The effects of irrigation and inter-row spacing on grain sorghum production. Israel J. Agric. Res. 14: 227 - 236.

Briggs, L.J. and Shantz, H.L 1913. The water requirements of plants. II. A review of literature. U.S. Dept. Agric. Bur. Plant Ind. Bull. 285.

De Wit, W. 1958. Transpiration and crop yields. Institute of Biological and Chemical Research on field crops and herbage. Wageningen, The Netherlands, Verse-Landvouwk, Onder Z. No. 64. 6-s, Gravenhage.

DMC. 1999. SADC Drought Monitoring Centre. Report on the capacity building workshop on seasonal rainfall forecasting and SARCOF forecast update of the JFM 2000 seasonal rainfall forecast, 6-17 December, 1999, Harare, Zimbabwe. DMC SARCOF Report No.5, 25 p.

Frère, M. and Popov, G.F. 1979. Agrometeorology crop monitoring and forecasting, FAO Plant production and Protection paper 17, FAO, Rome, 64 p.

Hanks, R.J. 1974. Model for predicting plant yield as influenced by water use. Agron. J. 66: 660-664.

Hanks, R.J., Gardner, H.R. and Florian, R.L 1969. Plant growth-evapotranspiration relations for several crops in the Central Great Plains. Agron. J. 60:30-34.

Hanks, R.L. and Hill, R.W. 1980. Modelling crop responses to irrigation in relation to soils climate, and salinity. Keterpress Enterprises, Jerusalem, 66 p.

Hill, R.W., Hanks, R.J. and Wright, J.L.1987. Crop yield models adapted to irrigation scheduling programs. Irrigation systems for the 21st century. Proceedings of the Irrigation & Drainage Div/ASCE, Portland, Oregon, July 28-30,1987 pp 699-706.

Hill, R.W. 1997. CRPSM - Crop growth and irrigation scheduling model. Software user manual. Biological & Irrigation Engineering Department. Utah State University, Logan, UT 84322-4105, 204 p.

Jensen, M.E. 1968. Water consumption by agricultural plants. In: T.T. Kozlowski (Eds.), Vol.2, Water deficits and plant growth. Academic press, New York.

Kassasse, C.T. 1992. Determination of effective length of growing season in Tanzania

M.Sc. dissertation, Sokoine University of Agriculture, Morogoro, 104 p.

Raes, D.H., H. Lemmens, P. Van Aelst, M. Vandenbulcke, and M. Smith. 1988. IRSIS- Irrigation Scheduling Information System, Vol. I, Ref. Manual No. 3. Laboratory of Land Management, K.U. Leuven, Belgium, 119 p.

Robertson, G.W., 1968. A biological time scale for a cereal crop involving day and night temperatures and photoperiod. Int. J. Biometeorology. 12(3): 191 - 223.

Smedema, L.K. and Rycroft, D.W. 1983. Land Drainage. Batsford Academic and Education Ltd, London, 376 p.

Snijders, T.A.B. 1986. Improving estimators of crop yield distributions by the use of historical rainfall data. In: (Eds), Proceeding of the Third International Conference on Statistical Climatology, Vienna pp 281 - 285.

Stern, P.C. and Easterling, W.E. (Eds.). 1999. Making Climate Forecasts Matter. National Academy Press, Washington D.C. 175 p.

Stewart, J.I., Misra, R.D. and Pruitt, W.O. 1975. Irrigation of corn and grain sorghum with a deficient water supply. Trans. ASCE 18 (2): 270 - 280.

Stewart, J.I., Danielson, R.E., Hanks, R.J., Jackson, E.B., Hagan, R.M., Pruitt, W.O., Riley, J.P. 1977. Optimizing crop production through control of water and salinity levels in the soil. Utah Water Research Lab. PR 151-1, Logan Utah. 191 p.