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Drought mitigation in Morocco: Setting an indicator for an early drought warning

A. Chafai Elalaouim, A. Ibrahimy and A. Berkane
National School of Agriculture, BP S/40, Meknes, Morocco
chafai_ali@yahoo.fr

SUMMARY – In order to alleviate the adverse effects of drought on agriculture in Morocco, we have developed an Indicator for an Early Drought Warning, based on the prediction of the three main cereal yields at any time of the growing season for a given Province. By comparison of the predicted yield with the statistical yield series, we can determine the drought severity and issue an Early Drought Warning when the predicted yield falls in the moderate or severe drought classes.

Key words: Drought, cereals, mitigation, Morocco, indicator.

RESUME – *"Atténuation de la sécheresse au Maroc : Mise au point d'un indicateur d'alerte précoce à la sécheresse". Dans le but de réduire les effets adverses de la sécheresse sur les productions agricoles au Maroc, nous avons élaboré un Indicateur d'Alerte Précoce à la Sécheresse basé sur la prévision des rendements des trois principales céréales à n'importe quel moment du cycle de ces cultures, au niveau d'une Province donnée. Par comparaison du rendement prévu avec la série statistique des rendements réels, on peut déterminer la sévérité de la sécheresse et donner une alerte précoce quand le rendement prévu se trouve dans la classe de sécheresse modérée ou sévère.*

Mots-clés : *Sécheresse, céréales, atténuation, Maroc, indicateur.*

Introduction

In Morocco, cereals (soft wheat, durum wheat and barley) are the main crops with low and very variable yields. During the last 25 years, Morocco has experienced more frequent and more severe droughts than even before with adverse effects on agriculture and the National Economy (Mokssit and El Khatri, 2001). The Moroccan agriculture depends on rain at nearly 85%; cereals occupy about two-thirds of the usable agricultural land with an average production estimated at 50 million quintals, and a coefficient of variation of 46% (Felloun and Laassiri, 2002). The average area planted to cereals does not vary much. The observed wide variability in production is due to fluctuations in average yields of cereals which, over the last 20 years, ranged from 0.5 tons per hectare (t/ha) to 1.5 t/ha, with a variation coefficient of 40%. This high variability of yields is mainly due to that of the rainfall (Berkane, 2004).

Through the experience of several countries that suffered from drought, it has become necessary to develop indicators to issue early drought warnings allowing farmers and decision makers to take the appropriate measures in order to reduce the impact of drought and alleviate its adverse effects on agricultural production and on people whose main income comes from agriculture.

For these reasons, we choosed as an Early Drought Indicator, the yield of cereals, because cereals are the main crop in Morocco and 99% of this crop area is rain fed. In addition, we have established for the majority of the provinces, over the past 16 years, a significant correlation between the three cereals yield and the annual rainfall. This correlation would be vastly improved if it also took into account rainfall distribution.

Based on these findings, the objective of this study is to develop a mathematical model that allows us to predict the yield of each of the three main cereals, soft wheat, durum wheat and barley, as a function of the decadal rainfall of the province, at anytime of the growing cycle. This model is the indicator that will trigger drought alerts at the regional level as a first step, and then at the national level, if necessary.

Methodology

The data on grain production and the rainfall of the period 1978 to 2003 by Province were collected from different directorates of the Ministry of Agriculture, as well as the Directorate of National Weather Service.

The models developed are time series models. Yield of soft wheat, durum wheat or barley is the variable to be explicated. Decadal rainfall of a given Province is the explanatory variable.

$$Y = a_0 + a_1 d_{1.11} + a_2 d_{2.11} + a_3 d_{3.11} + a_4 d_{1.12} + a_5 d_{2.12} + a_6 d_{3.12} + a_7 d_{1.1} + a_8 d_{2.1}$$
$$+ a_9 d_{3.1} + a_{10} d_{1.2} + a_{11} d_{2.2} + a_{12} d_{3.2} + a_{13} d_{1.3} + a_{14} d_{2.3} + a_{15} d_{3.3} + a_{16} d_{1.4} + a_{17} d_{2.4} + a_{18} d_{3.4} + \varepsilon_t$$

where:

(i) Y: yield in 0.1 t/ha per hectare, this is the dependant variable.

(ii) di j: d represents decadal rainfall in millimeters, i is the year number in the decade, j is the month number in the year (from 1 to 12).

(iii) a_0 , a_1 and so on represent the coefficients of regression.

(iv) ε_t represents the model error, which means all the yield explaining factors that are not linked to decadal rainfall.

For the selection of variables to keep, we used the method that consists in the gradual elimination of explanatory variables. This procedure consists, for the complete model with k explanatory variables, in eliminating step by step variables whose value of Student's t is below the critical threshold. To validate the model, we used tests, namely Kolmogorov-Smirnov testing, the stability test by the recursive regression and Breusch-Godfrey testing.

After determining the yield of each cereal specie using the preceding model, we used this yield to determine the significance of the severity of the agricultural drought. We have identified five classes of agricultural drought on the basis of yields observed in the last 25 years, for each Province. The method of the standard deviation was used. This classification is illustrated in Table 1.

Table 1. Agricultural drought severity classes as a function of yield, according to the standard deviation index

Drought severity classes	Yield threshold†
Severe drought	Ay - $\sigma \leq$ Yi < Ay - 2σ
Moderate drought	Lu $\leq$ Yi < Ay - σ
Normal year	Lw $\leq$ Yi < Lu
Good year	Lu $\leq$ Yi < Ay + σ
Very good year	Yi $\geq$ Ay + 2σ

† Ay = Average yield; Yi = year i yield; σ = Standard deviation; Lw = Confidence interval lower limit; Lu = Confidence interval upper limit.

Results and discussion

We established for each of Morocco's 33 Provinces the three equations for the prediction of yield, respectively for durum wheat, bread wheat, and barley. For each equation, we indicate the coefficient of determination and p-value. Of course this yield estimation can be done at any point in the cycle of crop, before maturity by replacing the values of decadal rainfall to come by the mean values of the province. The yield estimation thus made assumes that the rest of the cycle of culture will take place normally. We will give as an example the equations for Ben Slimane Province.

Durum wheat: R^2: 0.99; p-value: 0.00623; Y (yield) in 0.1 t ha^{-1}

$$Y = - 13.999 + 0.083\ d_{2.11} + 0.158\ d_{3.11} - 0.443\ d_{1.12} + 0.204\ d_{2.12} + 0.059\ d_{3.12} + 0.342\ d_{1.1} + 0.260\ d_{2.1} + 0.167\ d_{1.2} - 0.335\ d_{2.2} + 0.326\ d_{3.2} + 0.426\ d_{1.3} - 0.313\ d_{2.3} + 0.654\ d_{3.3}$$

Bread wheat: R^2: 0.99; p-value: 0.00719; Y (yield) in 0.1 t ha^{-1}

$$Y = - 17.317 + 0.161\ d_{2.11} + 0.195\ d_{3.11} - 0.516\ d_{1.12} + 0.235\ d_{2.12} + 0.065\ d_{3.12} + 0.394\ d_{1.1} + 0.286\ d_{2.1} + 0.195\ d_{1.2} - 0.460\ d_{2.2} + 0.406\ d_{3.2} + 0.515\ d_{1.3} - 0.416\ d_{2.3} + 0.784\ d_{3.3}$$

Barley**:** R^2: 0.99; p-value: 0.00006; Y (yield) in 0.1 t ha^{-1}

$$Y = - 12.851 + 0.095\ d_{2.11} + 0.104\ d_{3.11} - 0.401\ d_{1.12} + 0.163\ d_{2.12} + 0.059\ d_{3.12} + 0.357\ d_{1.1} + 0.235\ d_{2.1}\ 1 + 0.130\ d_{1.2} - 0.344\ d_{2.2} + 0.292\ d_{3.2} + 0.302\ d_{1.3} - 0.242\ d_{2.3} + 0.649\ d_{3.3}$$

After determining the expected yield for a given species using the models below, we look at the following table to situate in the corresponding class performance to determine the severity of the agricultural drought.

When a given Province yields are estimated to fall in the moderate or severe drought classes, a Drought Warning is issued to enable farmers and decision makers to take the necessary measures to minimize the adverse effects of drought on crops and farmers whose income comes mainly from rain-fed agriculture.

Table 2. Drought severity classes according to yield (0.1 t/ha^{-1}) for durum wheat, bread wheat, and barley, for Ben Slimane Province.

Drought severity classes	Durum wheat yield	Bread wheat yield	Barley yield
Severe drought	$Y < 6.3$	$Y < 7.5$	$Y < 5.9$
Moderate drought	$6.3 \le YR < 10.2$	$7.5 \le Y < 11.8$	$5.9 \le Y < 9.3$
Normal year	$10.2 \le Y < 17.6$	$11.8 \le Y < 20$	$9.3 \le Y < 15.6$
Good year	$17.6 \le Y < 21.5$	$20 \le Y < 24.2$	$15.6 \le Y < 19$
Very good year	$Y \ge 21.5$	$Y \ge 24.2$	$Y \ge 19$

We can observe that for the three species, in all the provinces, the coefficients of determination are very highly significant ($R^2 > 0.97$). The error made by using these equations is negligible. In addition, we determined the strength of the models to predict the performance by province, by comparing the productions planned with the real production. The results show that the models are perfectly valid and reliable, given that the error (the difference between the estimated and the actual yields) for the three grain species is extremely low (less than 1 kg). In addition, the cusum and cusum sq statistics showed that the proposed model for estimating the yield is perfectly stable and can be used to forecast the yields of the coming years.

Conclusion

Now, Morocco has a valid and reliable Indicator for an Early Drought Warning, at the Regional level and the National level. To use this Indicator, we only need decadal rainfall for every Province. In addition, this Indicator provides the degree of drought severity and the expected yield of the three main cereals. To enable easy and interactive use and of this model, a software is being developed.

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