Crop Monitoring as an
E-agricultural tool in
Developing Countries

WHEAT YIELD PREDICTION FOR MOROCCO

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EXECUTIVE SUMMARY

Crop yields can be assessed using vegetation indices retrieved from coarse resolution sensors on satellites such as TERRA MODIS or SPOT-VEGETATION. The most used and the simplest vegetation variable is NDVI (Normalized Difference Vegetation Index). This variable is widely used as predictors in crop yield forecasting models. This work-package has objectives to analyses all biophysical, technological and meteorological factors that affect wheat yield on the Huaibei plain and establish the yield prediction models for each province in Morocco using NDVI and its derivatives as explanatory variables.

1. Introduction

Cereals are a strategic food in Morocco. With 210 kg per capita, the consumption is one of the highest in the world, but it is not entirely covered by local production. The three major cereal crops (soft wheat, durum wheat and barley), are designed for various specific end uses depending on the crop. The grains of barley are used primarily (97%) to feed animals, with a small share (7%) being used for human consumption in the form of flat bread or semolina. Wheat grains are used exclusively in human diet, basically in the form of bread and pasta, and also biscuit and semolina. At the industrial level, soft wheat is used for the production of bread and biscuit, while durum wheat is used for the production of couscous and pasta. At the household level or artisanal small businesses, wheat is used to produce a multitude of products made from flour and wheat grain. Soft wheat has become the largest contributor to food security of the country's due to the large consumption of leavened bread by Moroccans (133 kg/person x year), accounting for two-thirds of the total cereal human consumption, followed by durum wheat which contributes to 25%. Because of the high demand on soft wheat for bread, cropped area increased on the expense of durum wheat, barley and fallow. Areas of durum wheat and fallow were reduced, while that of barley shifted to drier areas. The market demand for soft wheat continues to increase due to population growth, while the agricultural area remains almost unchanged, which limits the alternatives for cereal grain provision in Morocco to the sole option of improving land productivity.

Cereals have large capacity to adapt to geographical, climatic, and cultural environmental conditions. They are grown all over the country, from the Sahara south to the Mediterranean border north, and from the Atlantic Ocean west to borders of Algeria east. Cereals occupy more than two-thirds of agricultural land (Figure 1). Although they are cultivated in 36 provinces, production is mainly concentrated in the coastal areas, followed by central and mountainous regions. Cereals are part of most crop rotations, in addition to continuous cereal cropping, and are grown on a wide range of soils, production systems and environments.

Cereal productivity of soft wheat, durum wheat and barley, is strongly influenced by rainfall, varying in space and time: in space, the northern regions are more productive than those in the south, ranging in a magnitude of 1 to 3.5, and in time, the yield varies from about 1 to 5, 3.6 Q/ha recorded during the dry crop season of 1999-2000 to 18.5 Q/ha recorded during the wet season of 2008 - 2009 (official agricultural Statistics, 1979-2011).
Production of soft wheat is concentrated in the Atlantic plains of the country, from arid zones south to wet zones north. The provinces that contribute most to wheat production are: Beni Mellal (11.4%), Sidi Kacem (10.0%), Kenitra (8.9%), Khemisset (6.7%), El Kalaa Sraghna (6.0%) El Jadida (5.7%), Settat (5.5%), Taounate (5.3%), Meknes (4.9%) and Fez (4.4%) (data series from 1990 to 2010). These ten provinces contribute more than two thirds (69%) of the country’s wheat production. Among these 10 provinces, eight provide

61% of the national production of durum wheat. Each one of the remaining provinces contributes less than 4% of the total soft wheat production.

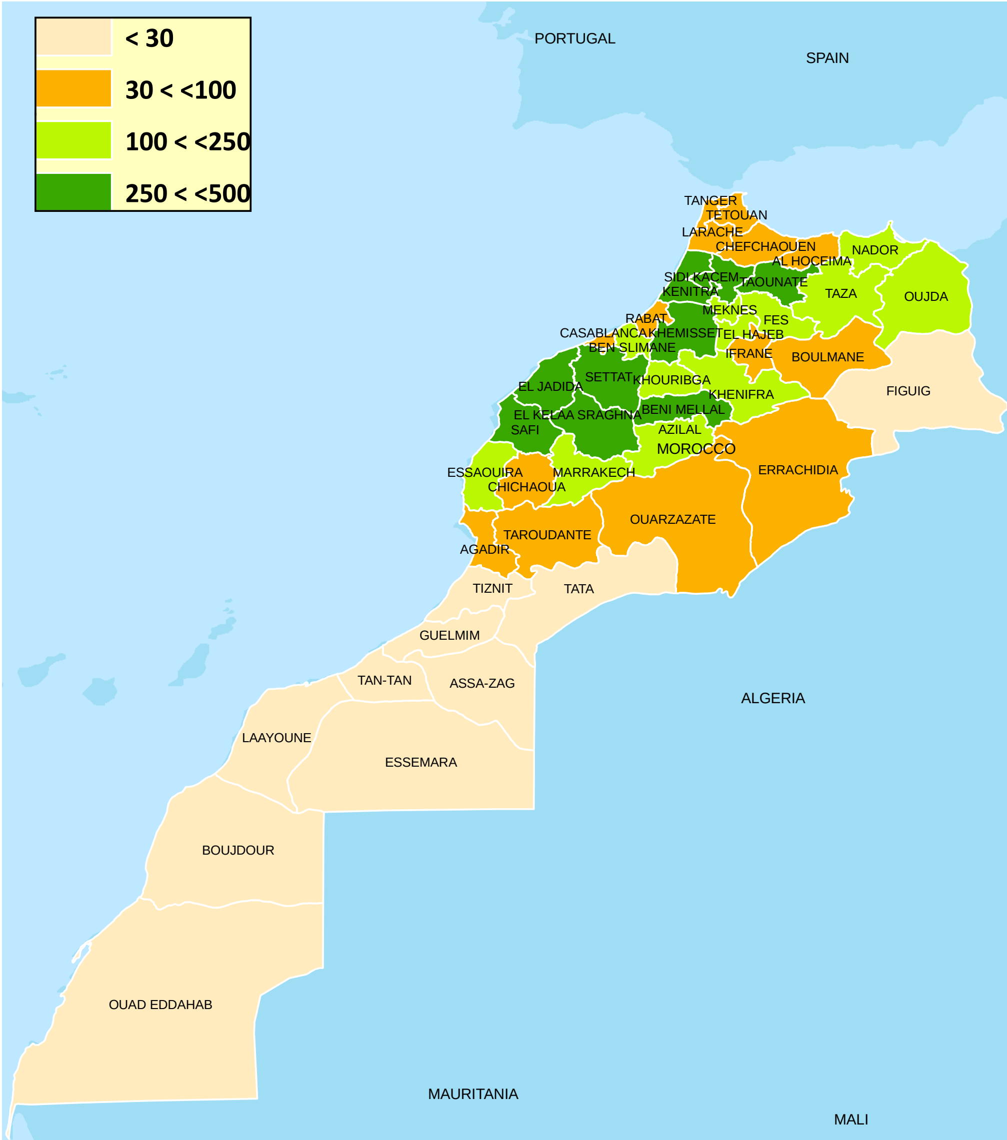


Figure 1: Provinces of Morocco with their average cereal production (x1000 tons) (1990-2010; Data source: Direction of Strategy and Statistics of the Ministry of Agriculture).

The provinces that contribute most to the country's production of durum wheat are: Settat (12.4%), El Jadida (10.9%), Taounate (9.3%), Taza (7.1%), El Kalaa Sraghna (6.1%), Safi (6.1%), Beni Mellal (5.1%) and Sidi Kacem (4.4%) (data series from 1990 to 2010). These eight provinces provide 61% of the national production of durum wheat. Each of the remaining provinces contributes less than 4% of the total durum wheat production.

Barley production is concentrated in arid and semi-arid zones and in mountainous areas.

The provinces that contribute the most to the national production of barley include: Settat (8.4%), El Jadida (7.2%), Safi (6.8%), Nador (6.6%), El Kalaa des Sraghna (6.1%), Essaouira (5.3%), Oujda (4.6%), Khouribga (4.5%), Taza (4.4%) and Marrakech (4.2%) (data series from 1990 to 2010). These ten provinces provide 58% of the country's production of barley. Each of the remaining provinces contributes less than 4% of the total barley production.

As mentioned above, the cereal production can be affected by many factors, such as technological, biophysical or climatological factors. Many of these drivers can be assimilated /modelled or estimated using remote sensing approaches. Since the year 80', the introduction of coarse resolution satellite sensors, starting with NOAA-AVHRR, provided a potential tool for an objective and near real-time observation on vegetation growth. Since then, other satellites payloaded with sensors of similar observation capability have joined the class, including SPOT-VGT in 1998 and Terra-MODIS in 2000. This category of sensors with a spatial resolution between 250 m and 1 km assume particularly well the task of vegetation monitoring thanks to their large geographic coverage and high revisiting frequency.

The monitoring can be usually achieved by analysing so-called biophysical variables or vegetation indices retrieved from these sensors. Normalized Difference Vegetation Index (NDVI) is the oldest and simplest vegetation variable to be computed and applied in the crop monitoring. In the study case of Morocco, the Index NDVI and its derivatives have been demonstrated as reliable yield predictors

Figure 2: a typical wheat field in Morocco

2. Data and methods

2.1. Data

2.1.1. Statistical data for wheat yield

The statistics of the wheat yield from 1961 to 2011 are accessible from the Department of Statistics and Strategy (DSS) of the Ministry of Agriculture.

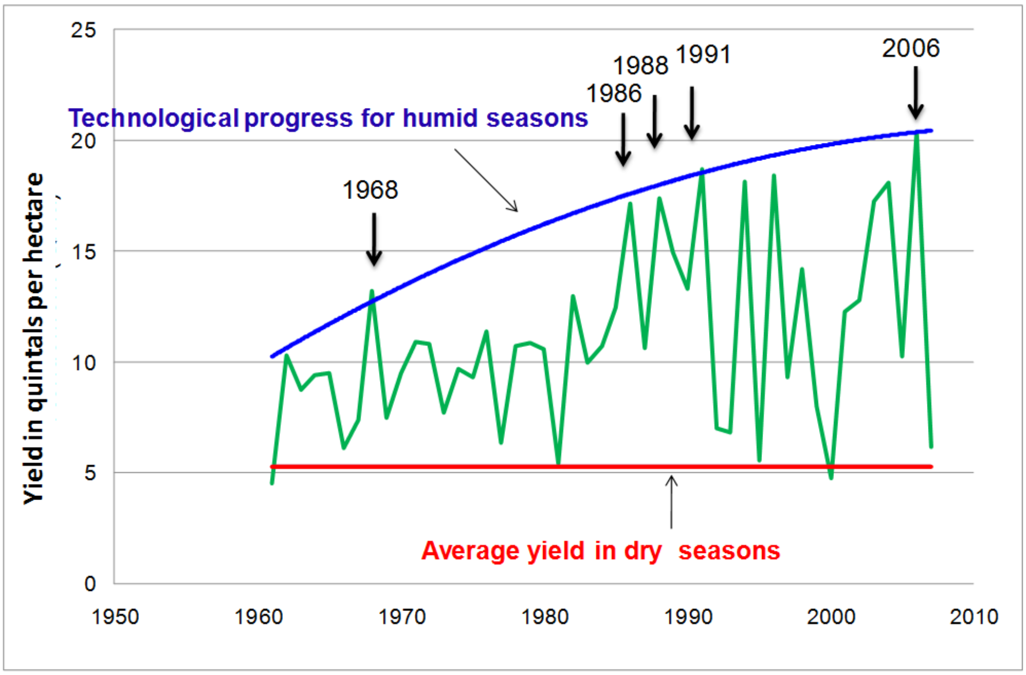


Figure 1: Soft wheat yield (quintals/hectare) during the 1961 and 2010 at national level. A technological trend was visible before 1990. Six yield records were realized during six humid seasons (1961-62, 1967-68, 1985-86, 1987-88, 1990-91 and 2005-06). The red line shows the average wheat yield during the dry growth years.

2.1.2. Remote sensing and other auxiliary Data

SPOT-VEGETATION imagery: the VGT-data for the Moroccan study area are expressed in the **INSPIRE-LAEA** projection system with a resolution of 1 km. As shown in figure 4, the selected ROI only covers the northern parts of the territory. It is bounded as follows:

- X: from 2 275 000 m to 3 385 000 m
- Y: from 765 000 m to 1 575 000 m
- Nr. of columns=1110, nr. of records=810, nr. of pixels=899

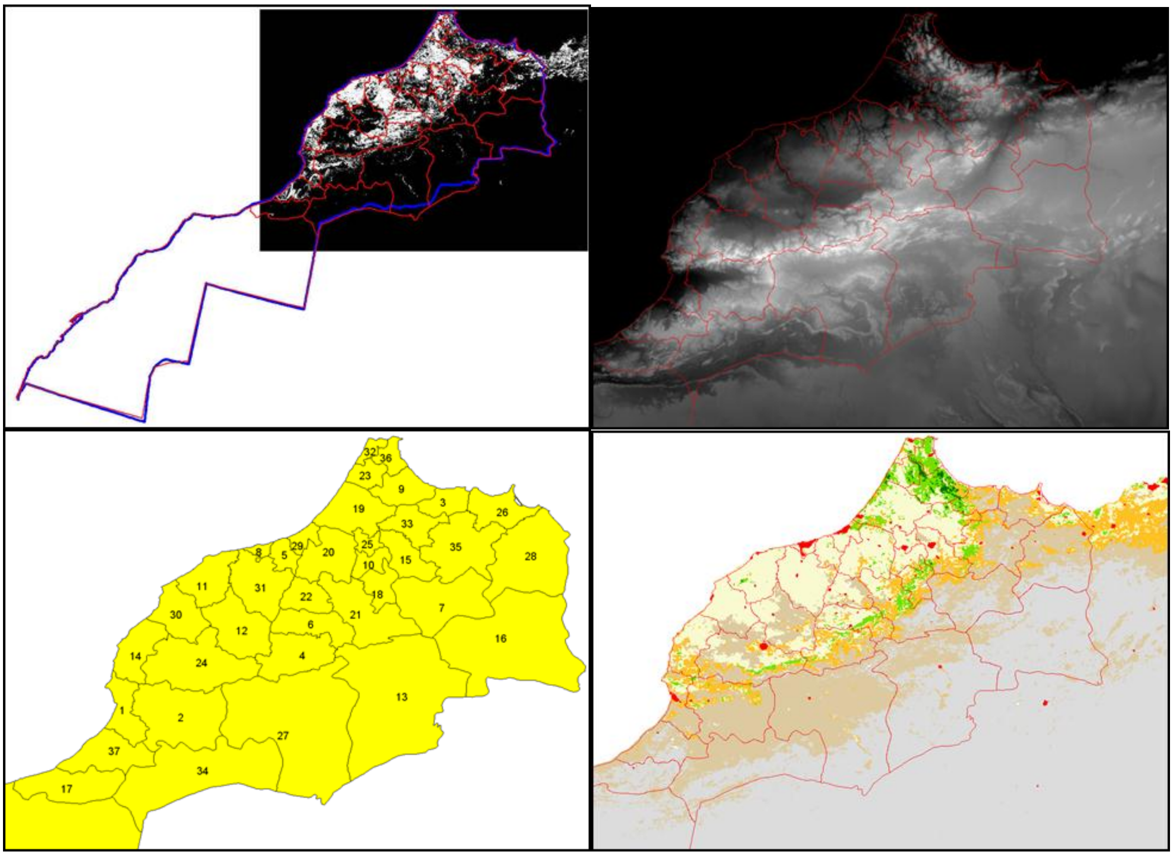


Figure 4: The up-left frame shows the Morocco national border (blue),its provinces border (red) and the analysed image block, in this case with the cropland AFI. The upright is an image of Digital terrain model GTOPO30. The lower-left frame shows the 38 considered provinces and the Region-IDs (see table for the province names). The lower-right frame is a quick look of The GLC2000 land use map. White=cropland in the northwest, green/brown=forests and shrubs mainly in the Atlas mountains, grey=desertic zones in the south and east, red=urban areas.

Table 1: The considered Moroccan provinces and their Region_ID numbers.

ID	NAME	ID	NAME	ID	NAME	ID	NAME
1	AGADIR	11	EL JADID	21	KHENIFRA	31	SETTAT
2	TAROUDAN	12	EL KELAA	22	KHOURIBG	32	TANGIER
3	AL HOCEI	13	ERRACHID	23	LARACHE	33	TAOUNATE
4	AZILAL	14	ESSAOUIR	24	MARRAKEC	34	TATA
5	BEN SLIM	15	FES	25	MEKNES	35	TAZA
6	BENI MEL	16	FIGUIG	26	NADOR	36	TETOUAN
7	BOULEMAN	17	GUELMIM	27	OUARZAZA	37	TIZNIT
8	CASABLAN	18	FRANE	28	OUJDA	38	LAAYOUNE
9	CHEFCHAO	19	KENITRA	29	RABAT		
10	EL HAJEB	20	KHEMISSE	30	SAFI		

Figure 5 show the phenology of wheat cultivated in Morocco

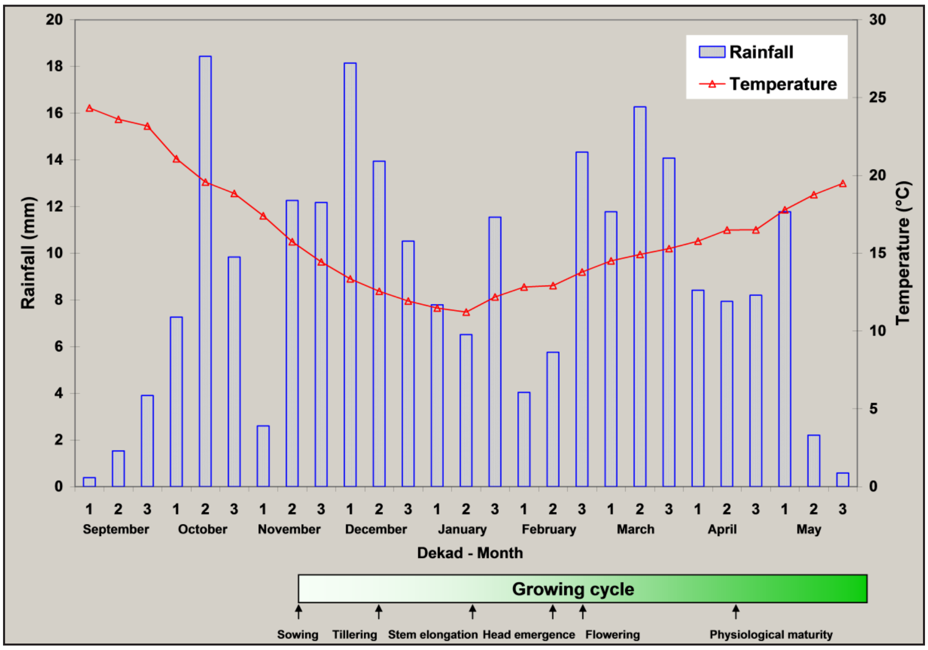


Figure 5: Phenology of wheat in Morocco

2.2. Method of pre-processing

The analysis is very similar to the one described the study area of Huaibei Plain (D44.1). Again, the considered ROI was extracted from the global datasets: GLC2000, GTOPO30 and the cropland AFI (GlCropV2). The SHP-file with the province boundaries was converted to raster format. In the resulting Regions-IMG, each pixel contains the REG_ID number (1-38) of the province to which it belongs (Figure 4 and Table 1).

As mentioned, satellite time series for Morocco were generated for the five concerned biophysical variables: i-NDVI, a-FAPAR, k-NDVI, b-FAPAR and y-DMP. As for the study region of Huaibei Plain, all the imagery covers the full period 1999-2010 (12 years, always with 36 dekads). The time series were extended during the project execution aiming integrating the approach to the CGMS-MAROC for yield forecasting purposes

The RUM-extraction was conducted:

- Separately for the five concerned variables: i-NDVI, a-FAPAR, k-NDVI, b-FAPAR, y-DMP.
- The mean values for all "cropland pixels" in each of the 38 provinces were computed.
- As "cropland" were considered all pixels having an area fraction of 100% in the cropland AFI (see Figure 4).

A "dedicated program" was then used to convert initial RUM-databases into easier-to-handle formats

3. Results

SHP-files with the boundaries of the country and its 38 provinces converted to the INSPIRE-LAEA projection (compatible with the VGTp-imagery). The associated DBF-file also includes the Region_ID numbers

Files MAROCn.csv, with n=1/2/3, containing the RUM-values in the three different formats, as in the case for the Huaibei Plain (D44.1)

Official statistics stored in the file "cereals 1979-2010_Bis.xls" were converted to TXT-files. They contain one line for each Region x Year, and each such line comprises three comma-separated values: Region_ID (table 2), Year and official yield (in qx/ha). Negative values are missing. There are four such files for four classes of crops: BLE_DUR, BLE_TEN, ORGE and CER_AUT, corresponding respectively durum wheat, soft wheat, barley and other cereals.

The forecasting models using NDVI at Provincial, agro-ecological zone and national levels show most consistency. The results are summarized in the Table 2 and Table 3.

Table 2: Regression models for cereal yield forecasting based on average NDVI (SPOT-VEGETATION) from February till March, at provincial level in Morocco.

	Soft wheat			Durum wheat			Barley		
Province	Intercept	Slope	R^2	Intercept	Slope	R^2	Intercept	Slope	R^2
AGADIR	-1,98	6,32	0,39	-3,04	8,87	0,31	-0,80	2,96	0,11
AL HOCEIMA	-0,51	4,26	0,70	-0,91	5,22	0,62	-0,36	4,04	0,58
AZILAL	-1,36	5,84	0,18	-1,48	5,53	0,19	-1,50	5,40	0,16
BEN SLIMANE	-3,72	8,46	0,74	-3,61	8,17	0,66	-1,87	4,80	0,52
BENI MELLAL	-1,29	5,18	0,44	-2,69	7,26	0,55	-3,21	6,86	0,54
BOULMANE	-0,20	2,94	0,12	0,18	2,05	0,04	0,27	1,78	0,04
CASABLANCA	-8,11	14,84	0,77	-8,41	14,87	0,68	-6,48	12,04	0,61
CHEFCHAOUEN	0,58	1,44	0,19	0,29	1,83	0,42	0,29	1,73	0,22
CHICHAOUA	-0,24	2,00	0,56	-0,23	2,18	0,34	-0,10	1,92	0,35
EL HAJEB	-3,47	9,01	0,45	-3,88	9,49	0,49	-3,38	8,43	0,40
EL JADIDA	-2,52	7,26	0,58	-1,55	5,58	0,22	-3,46	7,74	0,73
EL KELAA SRAGHNA	-0,98	4,55	0,70	-0,98	5,03	0,58	-0,99	4,02	0,78
ERRACHIDIA	2,47	-1,21	0,00	-0,61	6,95	0,04	2,51	-1,55	0,00
ESSAOUIRA	-2,23	7,17	0,73	-2,64	8,50	0,50	-1,55	5,44	0,71
FES	-2,80	7,19	0,81	-2,83	7,14	0,64	-1,69	4,68	0,65
IFRANE	0,91	0,44	0,00	-1,20	5,08	0,29	-0,39	3,38	0,20
KENITRA	-2,21	6,88	0,32	-2,37	6,87	0,43	-1,14	4,29	0,22
KHEMISSET	-3,38	8,47	0,76	-3,40	8,03	0,80	-1,97	5,45	0,72

KHENIFRA	-1,37	4,91	0,39	-1,48	5,01	0,44	-1,18	4,42	0,35
KHOURIBGA	-1,33	4,02	0,69	-1,03	3,29	0,52	-1,24	3,87	0,61
LARACHE	1,23	0,99	0,02	0,84	1,20	0,08	0,06	2,25	0,25
MARRAKECH	-0,37	2,88	0,24	-0,70	3,70	0,35	-0,77	3,50	0,40
MEKNES	-2,43	6,37	0,47	-3,12	7,67	0,68	-2,97	6,93	0,75
NADOR	0,43	2,53	0,13	0,08	2,22	0,30	0,56	1,11	0,09
OUARZAZATE	2,68	-2,94	0,13	0,00	0,00	0,00	0,96	0,97	0,02
OUJDA	-0,09	3,14	0,14	-0,53	3,95	0,49	-0,36	3,29	0,42
RABAT	-1,16	3,90	0,27	-3,02	6,69	0,79	-2,38	5,60	0,77
SAFI	-1,65	5,51	0,68	-1,55	5,49	0,84	-1,35	4,57	0,81
SETTAT	-2,08	5,31	0,78	-2,18	5,67	0,71	-2,28	5,63	0,66
SIDI KACEM	-4,03	8,86	0,64	-4,35	9,06	0,67	-2,22	5,44	0,58
TANGER	-0,64	3,64	0,25	-0,62	3,28	0,36	0,44	1,54	0,22
TAOUNATE	-2,50	6,62	0,79	-2,10	6,01	0,76	-1,49	4,40	0,66
TAROUDANTE	-1,14	5,02	0,35	-0,23	3,50	0,15	-0,96	3,82	0,31
TAZA	-0,48	4,57	0,35	-0,48	5,07	0,35	0,12	2,69	0,26
TETOUAN	1,98	-0,83	0,03	1,80	-0,73	0,03	0,97	0,77	0,02
TIZNIT	-0,18	1,69	0,44	0,00	0,00	0,00	-0,41	2,04	0,60

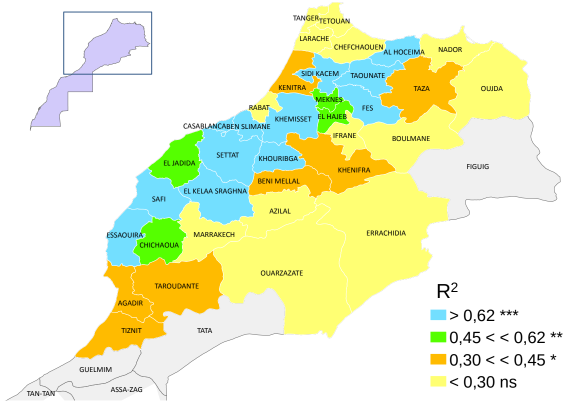
Table 3: Regression models for cereal yield forecasting based on average NDVI (SPOT-VEGETATION) from February till April, at provincial level in Morocco.

	Soft wheat			Durum wheat			Barley		
Province	Intercept	Slope	R^2	Intercept	Slope	R^2	Intercept	Slope	R^2
AGADIR	-2,10	6,74	0,48	-3,46	10,06	0,40	-0,80	2,96	0,11
AL HOCEIMA	-0,86	5,08	0,89	-1,26	6,04	0,74	-0,36	4,04	0,58
AZILAL	-2,44	8,33	0,32	-2,84	8,63	0,40	-1,50	5,40	0,16
BEN SLIMANE	-3,95	9,53	0,85	-3,74	9,06	0,74	-1,87	4,80	0,52
BENI MELLAL	-1,06	5,17	0,34	-2,63	7,69	0,49	-3,21	6,86	0,54
BOULMANE	-0,84	4,45	0,20	-0,98	4,78	0,15	0,27	1,78	0,04
CASABLANCA	-5,82	12,54	0,72	-6,13	12,60	0,64	-6,48	12,04	0,61
CHEFCHAOUEN	0,29	2,01	0,26	0,00	2,39	0,49	0,29	1,73	0,22
CHICHAOUA	-0,37	2,62	0,66	-0,40	2,95	0,42	-0,10	1,92	0,35
EL HAJEB	-4,18	10,50	0,62	-4,58	10,99	0,65	-3,38	8,43	0,40
EL JADIDA	-2,45	7,92	0,64	-1,42	5,96	0,23	-3,46	7,74	0,73
EL KELAA SRAGHNA	-1,12	5,31	0,71	-1,27	6,26	0,66	-0,99	4,02	0,78
ERRACHIDIA	0,91	2,29	0,00	-2,29	10,69	0,07	2,51	-1,55	0,00
ESSAOUIRA	-2,29	7,88	0,80	-2,87	9,77	0,59	-1,55	5,44	0,71
FES	-2,98	7,74	0,86	-2,95	7,57	0,68	-1,69	4,68	0,65
IFRANE	0,39	1,50	0,02	-2,12	6,87	0,50	-0,39	3,38	0,20
KENITRA	-3,64	9,50	0,45	-3,84	9,56	0,61	-1,14	4,29	0,22

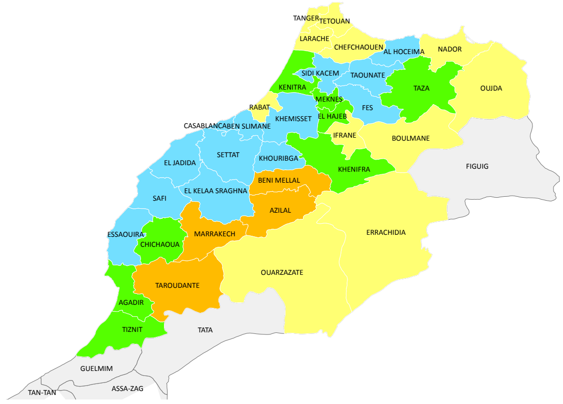
KHEMISSET	-3,62	9,29	0,85	-3,60	8,75	0,89	-1,97	5,45	0,72
KHENIFRA	-1,87	5,93	0,56	-1,83	5,72	0,55	-1,18	4,42	0,35
KHOURIBGA	-1,59	4,74	0,82	-1,36	4,12	0,71	-1,24	3,87	0,61
LARACHE	1,43	0,65	0,01	0,73	1,38	0,08	0,06	2,25	0,25
MARRAKECH	-0,73	3,87	0,37	-1,07	4,77	0,49	-0,77	3,50	0,40
MEKNES	-2,56	6,88	0,52	-3,37	8,42	0,77	-2,97	6,93	0,75
NADOR	-0,12	4,05	0,27	-0,24	3,12	0,47	0,56	1,11	0,09
OUARZAZATE	2,56	-2,67	0,10	0,00	0,00	0,00	0,96	0,97	0,02
OUJDA	-0,68	4,85	0,29	-1,02	5,34	0,76	-0,36	3,29	0,42
RABAT	-1,24	4,31	0,29	-3,19	7,43	0,85	-2,38	5,60	0,77
SAFI	-1,66	6,25	0,71	-1,49	6,07	0,84	-1,35	4,57	0,81
SETTAT	-2,20	6,03	0,88	-2,36	6,55	0,82	-2,28	5,63	0,66
SIDI KACEM	-5,22	11,07	0,84	-5,32	10,91	0,81	-2,22	5,44	0,58
TANGER	-1,04	4,25	0,24	-1,00	3,85	0,35	0,44	1,54	0,22
TAOUNATE	-3,12	7,76	0,89	-2,69	7,10	0,87	-1,49	4,40	0,66
TAROUDANTE	-1,27	5,51	0,43	-0,39	4,00	0,20	-0,96	3,82	0,31
TAZA	-0,91	5,62	0,51	-0,91	6,10	0,49	0,12	2,69	0,26
TETOUAN	1,69	-0,31	0,00	1,52	-0,22	0,00	0,97	0,77	0,02
TIZNIT	-0,29	2,10	0,48	0,00	0,00	0,00	-0,41	2,04	0,60

As we can see at provincial level, the consistency of the forecasting, represented by the coefficient of determination, improves, although slightly when we use the average of NDVI value between the months of February and April. Figure 6 shows the classification and spatial distribution of the provinces according to their forecast consistency in terms of cereal yields.

Soft wheat

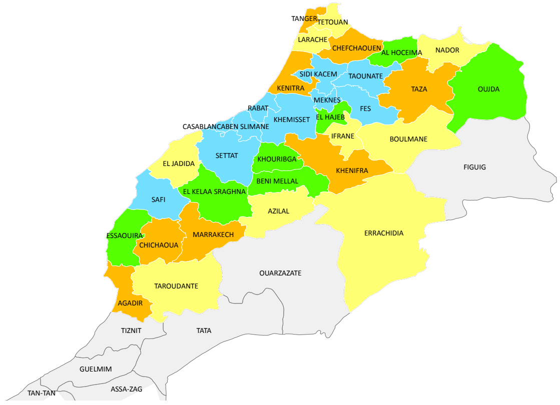


February to March

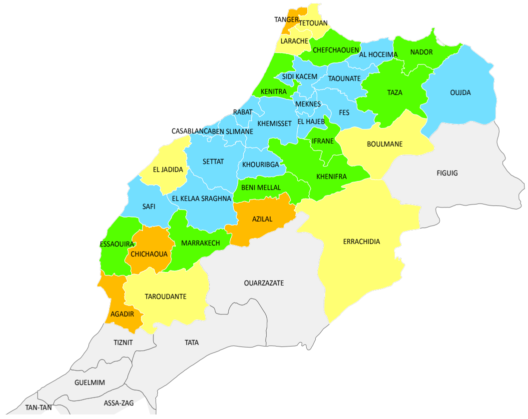


February to April

Durum wheat

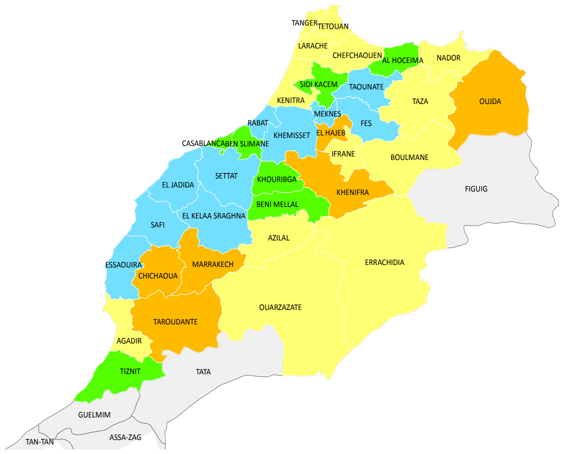


February to March

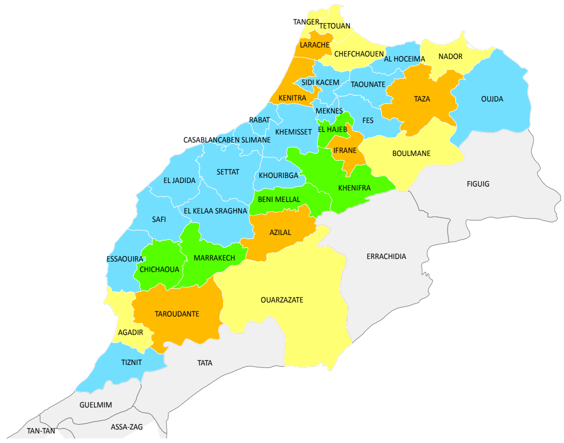


February to April

Barley



February to March



February to April

Figure 6: Mapping of four classes of coefficient of determination (R^2) of the linear regression models between yields of soft wheat, durum wheat and barley, and average dekad NDVI (SPOT-VGT) from February till March and from February till April.

The similar trend has also been observed at national level where the consistency of forecasting improves along with the advance of the growth season (Figure 7).

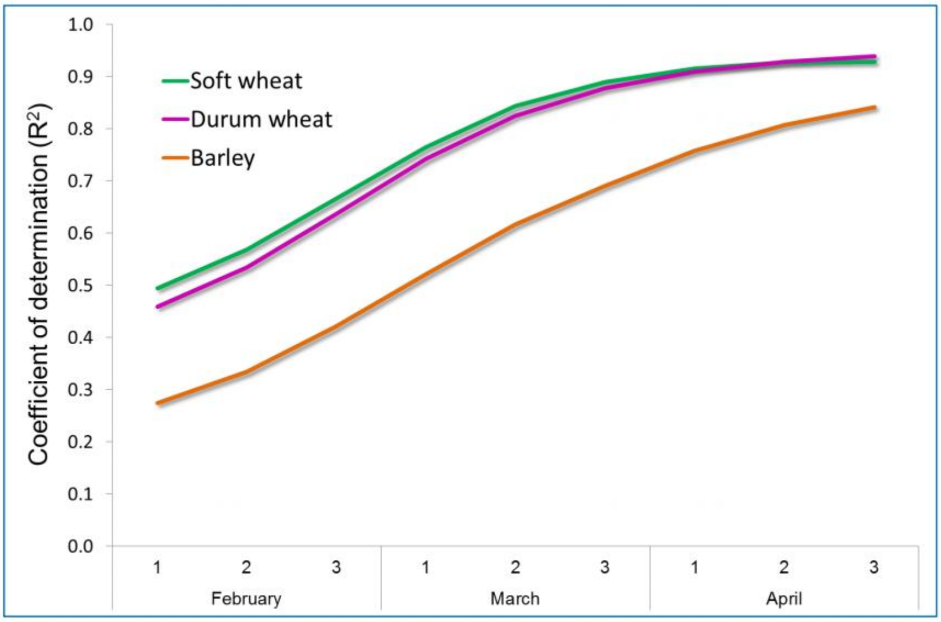


Figure 7: Coefficient of determination (R^2) of regression models between yields of the three main cereals (soft and durum wheat, and barley) in Morocco, and average NDVI (SPOT VGT), at the national level (data from 1999 to 2011), by step of one dekad, since the 1st dekad of February.

4. Conclusion

Compared to the approaches using weather data coming from ground stations, indicators derived from remote sensing, such as NDVI, have the advantage of being available throughout the extent of the country, without discontinuity at high spatial and temporal resolutions (in "raster" form, known as pixel), which is well suited for crop yield forecasting. Forecasts can be performed operationally at the levels of the provinces, agro-ecological zones and national level. Forecasted yield for each province can even be aggregated to national level, proportionally to their respective cropped areas, for providing yield forecast for the entire country. This approach requires more computational workload but with better accuracy. The coefficients of determination (R^2) of these models were high, ranging between 72 and 98%, except in the arid southern provinces of the country, which contribute little to the total national production. These regression models were relatively stable, since their coefficients of determination in cross-validation (R_p^2) were still between 59 and 94%. Furthermore, forecasts were relatively accurate and can be conducted early in the growth season, for example, two months prior to harvests.

A recrudescent interest of these statistical approaches has been prompted by the growing availability of remote sensing data, over long time series, and by information technology advances, allowing storage, processing and analysis of large amounts of datasets. Furthermore, statistical forecasting approaches were used to be criticized as the available time series, on which the analyses were based, were short or limited in time, during which the “outlier” or very infrequent events may not be included. This criticism appears less plausible in the case of Morocco, due to the high variability of climate and geography. In other words, the probability of encountering climatic seasons outside the range of historical variation is always possible, but nevertheless reduced due to the extreme cropping seasons experienced, both very dry (1994-1995, 1996-1997, 1999-2000, 2000-2001 and 2004-2005) and very humid (1995-1996, 2008-2009, 2009-2010 and 2010-2011).