academicJournals

Vol. 9(49), pp. 3519-3530, 4 November, 2014
DOI: 10.5897/2014.9130
Article Number: 6E775FF48871
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Assessment of the severity and impact of drought spells on rainfed cereals in Morocco

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Received 6 September, 2014; Accepted 7 November, 2014

Drought is a major factor affecting cereal production in most the rainfed areas of West Asia and North Africa. Recent increases in drought frequency in Morocco have resulted in the yields of field crops being extremely variable and generally low. The objective of this study is to assess drought severity in the main cereal production areas of Morocco and to evaluate its effects on grain yield. Also the study seeks to evaluate if the standardized precipitation index (SPI) may be used as a tool to predict drought and crop yield early in the season. Data analysis showed that for the period 1988 to 2008, yields fluctuated from 150 to 3000 kg/ha with a coefficient of variation of between 30 and 50% in the north and 60 and 70% in the south. Based on the SPI, the regions studied experienced, on average, a drought once every 2.6 years. However, very severe droughts were observed only once in 7 years. The SPIs computed for the periods October to June and January to March were highly correlated. Moreover, there was a high positive correlation between the yield and the SPI calculated for the period January to March. The coefficients of determination varied between around 0.20 and 0.62 for bread and durum wheats, and between 0.28 and 0.69 for barley. It is concluded that soil moisture levels during the tillering and stem elongation periods of the cereals are the most important determinants of yield. Hence an SPI computed for the period January to March can be used to predict drought severity and yields early in the season.

Key words: Rainfall, drought, cereals, yield, standardized precipitation index, predictions

INTRODUCTION

Morocco is characterized by low rainfall and high fluctuations in the amount of precipitation. Average rainfall decreases from north to the south and from west to the east of the country.

Agriculture in Morocco is highly dependent on climatic conditions as shown by the high correlation observed between precipitation levels and agricultural value-added (Ouraich and Tyner, 2012). Moreover, the effects of drought on agriculture are always measured in relation to their impact on cereal production, because these crops are highly sensitive to climatic conditions, as they are mainly grown under rainfed conditions. Moreover, they represent 55% of the total value-added of crop production and occupy 65% of the agricultural area. However,

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because of recurrent droughts during the period 1980 to 2011 (ONICL, 2012) the national average production of cereals was affected and, hence, imports were, on average, 2.6 million tonnes, which represented half of the Moroccan production. The effect of drought will be exacerbated by climate change because of its effects on rainfall and temperature. Recent studies (Gommes et al., 2009) have shown that by the end of the 21st century, rainfall, in Morocco is likely to decrease by 20 to 40% and the temperature will increase by 3 to 6°C, depending on the region.

Yields of rainfed cereals are affected by rainfall amounts and their distribution during the season. This effect can vary depending on the soil characteristics, cultivation practices, and the genotype. However, in the Mediterranean farming systems of the Western Australian wheat belt, crop yields are influenced primarily by the amount and distribution of rainfall and the soil’s capacity to hold moisture (Lawes et al., 2009). In fact, Christopher et al. (2008) indicated that the soil depth associated with the soil’s capacity to retain moisture in the presence or absence of rainwater, determined wheat productivity. Busscher et al. (2001) stated that corn yield was limited by deep compacted strata because these reduced root exploration within the soil profile. Richards (2008) specified that the increase in depth explored by the roots and the root density of the cereal allow increased water and nutrient absorption from the soil, which increases productivity.

In Morocco, there are three main periods of drought; the early drought that occurs in the autumn and usually decreases the stand establishment of the crop; the mid-season drought that can reduce the onset of kernels, and the late or terminal drought that usually negatively affects grain filling. Under these conditions of water scarcity, one of the potential strategies to increase and stabilize yields is to capture more rainwater for use in transpiration, to use the fixed carbon dioxide more effectively in producing biomass, and to convert more of the biomass into grain (Passioura, 1977, 2006). Despite the importance of both the source (biomass production) and sink (grain production) in the elaboration of cereal yields illustrated by this strategy, it was argued that only a relatively small fraction of the whole growing period is actually critical to the determination of yield (Otegui and Slafer, 2004). This is, in general, the period when the number of grains per unit land area is largely determined in response to the growing/partitioning conditions of the crops.

Drought indices are used to characterize drought and to provide spatial and temporal representations of its occurrence (Pashiardis and Michaelides, 2008) and severity. However, some of these indices are inaccurate and others are difficult to calculate. The Palmer Drought Stress Index (PDSI), for example, developed by Palmer (1965) is very effective in the evaluation of agricultural drought because it uses not only historical precipitation data; but also those of temperature and available water. The disadvantages of using this index is that it does not allow the detection of drought occurrence on time and it is less adapted to areas characterized by frequent extreme situations of the climate, such as the ones we usually observe in the dry areas of WANA (Karrou, 2006). In this study, we opted to use the standardized precipitation index (SPI) to evaluate drought severity and the effects of this climatic hazard on cereal production during the last two decades. This index was chosen because of its simplicity, the possibility to describe drought on different time scales, and its standardization, which ensures independence from the geographical position of the measuring stations. (Pashiardis and Michaelides, 2008). The SPI is calculated from the monthly precipitation data. It was developed by Mckee et al. (1993) to quantify the precipitation deficit for multiple time scales that reflect the impact of drought on the availability of the different water resources, including rainfall. The SPI was also selected because precipitation is not normally distributed; therefore, absolute rainfall values are usually more poorly correlated with yields than when the rainfall values are standardized (Teigen and Thomas, 1995). Yamoah et al. (2000) demonstrated for maize that up to 64% of the yield variability was explained by the SPI in a curvilinear relationship. According to these authors, the objective in relating SPI as a function of yield is to advise farmers on how to adjust their cropping plans ahead of time to maximize returns or reduce costs.

The objectives of this study are to evaluate how SPIs, calculated for the main periods of cereal growth and development, are linked to yield and determine if this index can be used to predict drought and help decision-makers better select the mitigation and preparedness measures to cope with this climatic hazard.

METHODOLOGY

Data collection

Long-term data on the average grain yields (1988 to 2008) of bread and durum wheats and barley in the major cereal production provinces of Morocco were provided by the Department of Statistics of the Ministry of Agriculture. These provinces represent the major agro-ecosystems existing in the country and their locations follow a rainfall gradient from the north (high rainfall) to the south (low rainfall) (Map 1). The wetter regions are represented in our study by Kenitra, Meknes, and Fes provinces, with average rainfalls for the last 20 years of 522, 450, and 442 mm, respectively. The relatively drier provinces, El Jadida, Safi, and Khouribga, had average precipitations of 387, 370 and 324 mm, respectively. Kenitra (high rainfall) and El Jadida (low rainfall) regions have some irrigated areas and hence the crops may have received some supplemental irrigation in the spring. Fes, Meknes, and Kenitra are located in the north of Morocco, El Jadida and Safi in the south, and Khouribga in the south east.

Rainfall data for the period 1988 to 2008 were provided by the National Directorate of Meteorology of Morocco. These data were collected from the synoptic weather stations of Fes (33° 97’ N, 4° 98’ S), Meknes (33° 88’ N, 5° 53’ S), Kenitra (34° 30’ N, 6° 60’ S),

Map 1. Map of Morocco showing the locations of the different regions studied.

El Jadida (33° 23' N, 8° 52' S), Safi (32° 28' N, 9° 23' S), and Khouribga (32° 87' N, 6° 97' S). The data show that the inter-year variations were very high for all the regions. The coefficient of variation is 42% for El Jadida, 38% for Kenitra, 33% for Fes, 31% for Meknes, 39% for Khouribga, and 47% for Safi.

Drought evaluation and statistical analyses

To evaluate drought severity in the selected regions, the SPI is calculated using the equation:

$$SPI = (Pi-Pm)/\sigma$$

Where Pi is the precipitation of year i at a given time scale and Pm is the mean precipitation of a long series of data. In our study, we used only 21 years because of the lack of data for the weather stations considered. σ is the standard deviation.

The SPI was computed for different time scales (3 and 9 months) using a series of monthly rainfall data covering the period of 1988 to 2008. These SPIs were determined for the three major growth periods of cereals: SPI October to December (SPI-OD), which corresponds to the germination and seedlings emergence (stand establishment) phases; SPI January to March (SPI-JM) when tillers and spikes are formed; and SPI April to June (SPI-AJ), which coincides with the grain filling time of cereals. We also calculated SPI October to June (SPI-OJ) because this 9 months period covers the whole life cycle of the cereal crops. These crops are usually planted in November/December and harvested in May/June depending on the species, the rainfall conditions of the year, and the region. Positive SPI values signify greater than median precipitation, while negative ones mean less. An SPI of zero indicates average conditions. A value greater than +2 indicates extremely humid conditions while one less than -2 generally indicates extremely dry conditions (Yamoah et al., 2000). SPIs of +0.99 and -0.99 are considered mild stress situations for cropping systems adapted to the region (McKee et al., 1993).

To evaluate the impact of drought severity on cereal yields, a simple regression analysis was performed between SPI levels and the yields of the bread wheat, durum wheat and barley. The

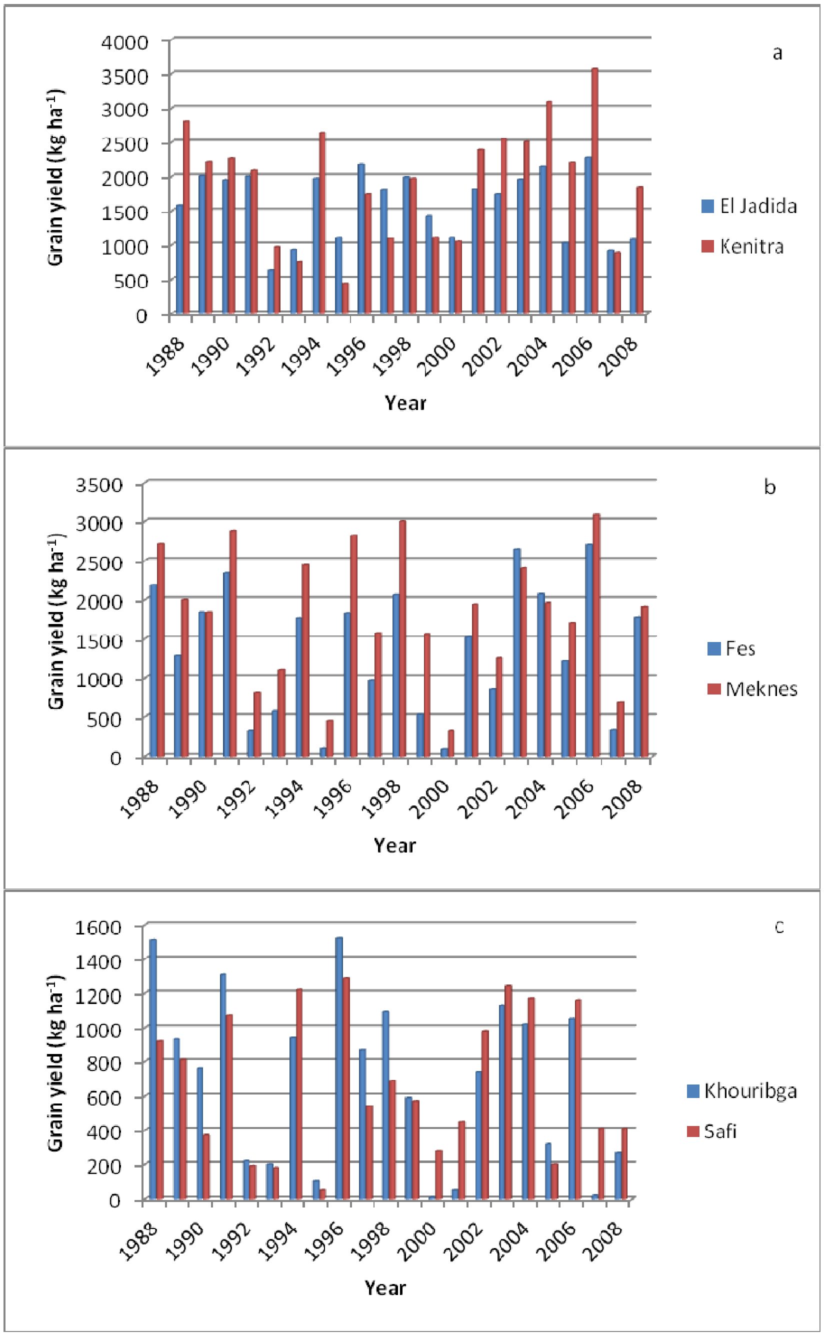

Figure 1. Variation of yield of bread wheat in six regions of Morocco from 1988 to 2008.

coefficients of determination (R^2) were computed for a series of yields for SPIs calculated for the periods October to December, January to March, April to June, and October to June.

RESULTS

Yield

Figures 1 to 3 present the changes in yields for wheat and barley in different regions from 1988 to 2008. The data show that, in general, the yield is low and variable in time and space and follows the trend of the rainfall. The coefficient of variation was very high, ranging from 30 to 55% in El Jadida and Kenitra, 45 to 65% in Fes and Meknes and 60 to 72% in Khouribga and Safi (the driest areas). On average, the yields of barley were lower than those of the bread and durum wheats.

In El Jadida and Kenitra there were the lowest yields

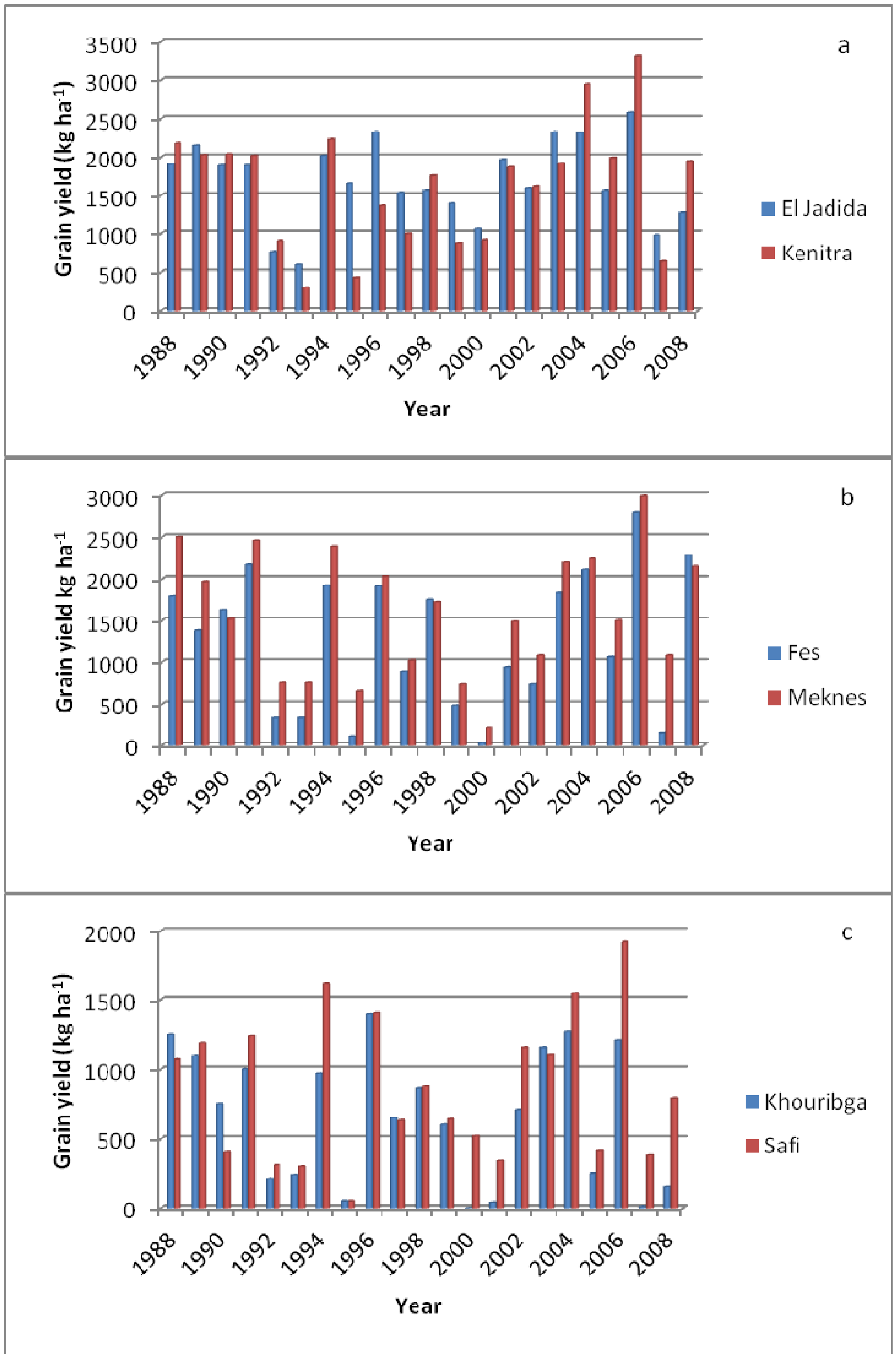

Figure 2. Variation of yield of durum wheat in six regions of Morocco from 1988 to 2008.

for all three cereal species in 1992, 1993, 2000, and 2007. They were, respectively in El Jadida, 630, 930, 1110 and 920 kg/ha for bread wheat, 770, 600, 1060 and 980 kg/ha for durum wheat and 450, 400, 270 and 600 kg/ha for barley. However, the yield of barley was very low – 100 kg/ha in 1995. For Kenitra, the analysis showed similar trend for 1992, 1993, 1995 and 2007 with respective yields of 970, 760, 440 and 890 for bread wheat, 910, 300, 430 and 640 kg/ha for durum wheat and 930, 350, 320 and 640 kg/ha for barley.

In El Jadida, high yields were realized for bread wheat in 1996 and 2006, for durum wheat in 1996, 2003, 2004, and 2006, and for barley in 1991 and 2006. In Kenitra high yields were obtained for bread and durum wheats in

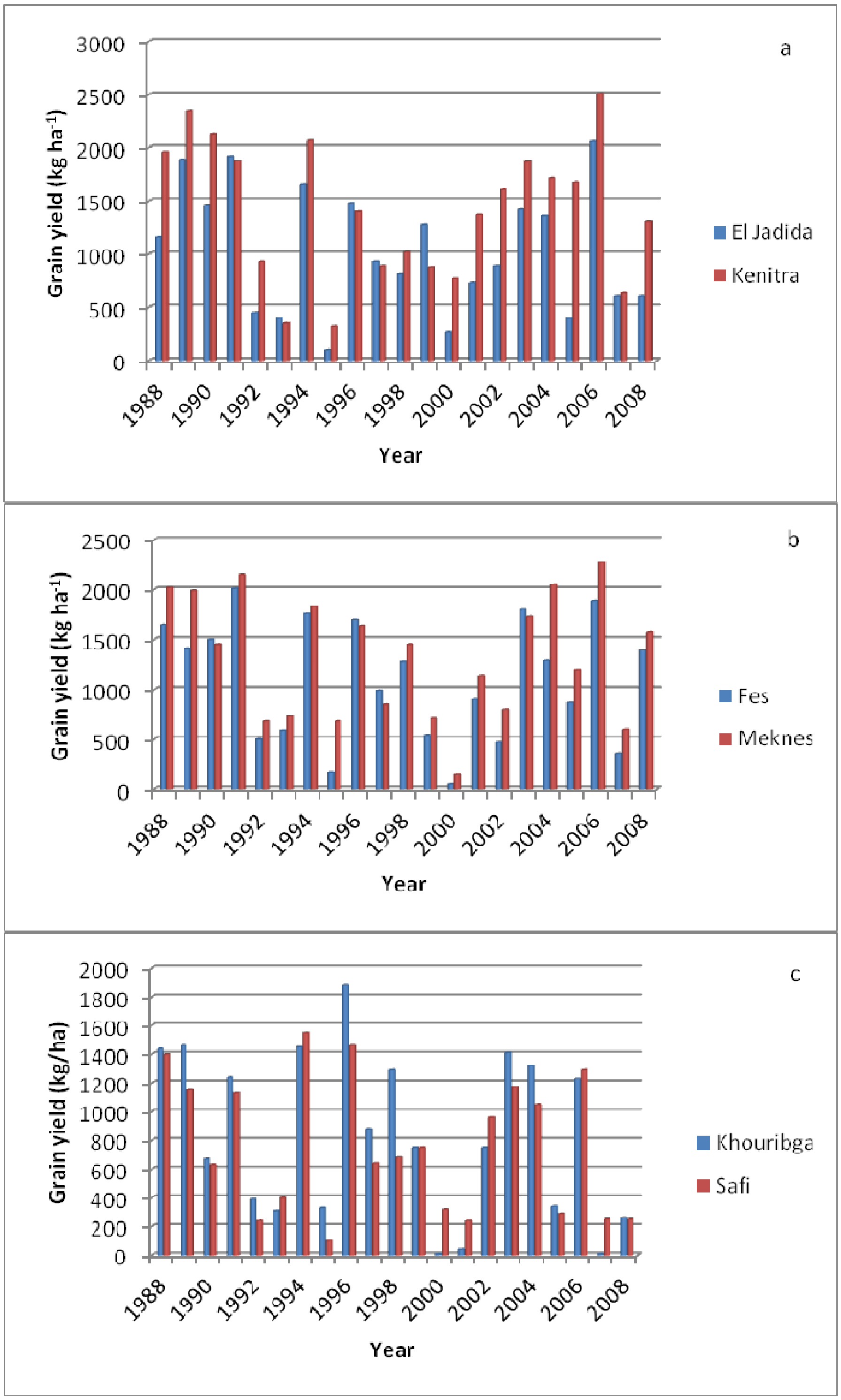

Figure 3. Variation of yield of barley in six regions of Morocco from 1988 to 2008.

2004 and 2006 and for barley in 1989 and 2006. The high values for durum wheat varied from 2000 to 2500 kg/ha in El Jadida and from 2500 to 3000 kg/ha for bread wheat in the case of Kenitra.

In Fes, low yields of bread wheat were obtained in 1992 (330 kg/ha), 1995 (100 kg/ha), 2000 (90 kg/ha), and 2007 (340 kg/ha). In Meknes the figures were 810 kg/ha in 1992, 450 kg/ha in 1995 and 330 kg/ha in 2000 and

690 kg/ha in 2007 (690 kg/ha). In Fes, yields of bread wheat were also low in 1993 (590 kg/ha) and 1999 (530). High yields of bread wheat were registered in Fes in 1991 (2340 kg/ha), 2003 (2640 kg/ha), and 2006 (2700 kg/ha) and in Meknes in 1991 (2880 kg/ha), 1996 (2820 kg/ha), 1998 (3000 kg/ha), and 2006 (3080 kg/ha).

For durum wheat, productivity in Fes was low in 1992 (330 kg/ha), 1993 (330 kg/ha), 1995 (110 kg/ha), 1999 (480 kg/ha), 2000 (30 kg/ha), and 2007 (150 kg/ha). The corresponding yields in Meknes were in 1992 (750 kg/ha), 1993 (750 kg/ha), 1995 (650 kg/ha), 1999 (730 kg/ha), 2000 (210 kg/ha), and 2007 (1080 kg/ha). In Meknes, 1997 was also a dry year and the yield of durum wheat was 1020 kg/ha. The highest yields of durum wheat were obtained in 2006 – 2800 kg/ha in Fes and 2990 kg/ha in Meknes.

For barley, low yields were registered in Fes in 1992 (500 kg/ha), 1993 (590 kg/ha), 1995 (170 kg/ha), 1999 (540 kg/ha), 2000 (50 kg/ha), 2002 (470 kg/ha), and 2007 (360 kg/ha). In Meknes low yields were recorded in 1992 (680 kg/ha), 1993 (730 kg/ha), 1995 (680 kg/ha), 1999 (710 kg/ha), 2000 (150 kg/ha), and 2007 (600 kg/ha).

In Fes, the high yields of barley were 2010 kg/ha in 1991 and 1890 kg/ha in 2006. In Meknes, high yields of barley were achieved in1988 (2020 kg/ha), 1989 (1990 kg/ha), 1991 (2150 kg/ha), 2004 (2050 kg/ha), and 2006 (2270 kg/ha).

For bread wheat, the average yield for Khouribga was 698 kg/ha and for Safi, 676 kg/ha. In Khouribga the years of low yields were 1992 (220 kg/ha), 1993 (200 kg/ha), 1995 (100 kg/ha), 2000 (10 kg/ha), 2001 (50 kg/ha), 2005 (320 kg/ha), and 2007 (20 kg/ha). In Safi low yields of bread wheat were obtained in 1990 (370 kg/ha), 1992 (190 kg/ha), 1993 (180 kg/ha), 1995 (50 kg/ha), 2000 (280 kg/ha), and 2005 (200 kg/ha). High yields of bread wheat were recorded in Khouribga in 1988 (1510 kg/ha), 1991 (1310 kg/ha), and 1996 (1520 kg/ha). In Safi high yields of bread wheat were obtained in 1994 (1220 kg/ha), 1996 (1290 kg/ha), 2003 (1240 kg/ha), 2004 (1170 kg/ha), and 2006 (1160 kg/ha).

For durum wheat, the average yield for Khouribga was 661 kg/ha and for Safi, 853kg/ha. Low durum wheat yields were obtained in Khouribga in 1992 (210 kg/ha), 1993 (240 kg/ha), 1995 (50 kg/ha), 2000 (0 kg/ha), 2001 (40 kg/ha), 2005 (250 kg/ha), 2007 (10 kg/ha), and 2008 (150 kg/ha). In Safi, the low yields of durum wheat were 400 kg/ha in 1990, 310 kg/ha in 1992, 300 kg/ha in 1993, 50 kg/ha in 1995, 340 kg/ha in 2001, and 380 kg/ha in 2007. The high yields that were obtained in Khouribga were 1250 kg/ha in 1988, 1100 kg/ha in 1989, 1000 kg/ha in 1991, 1400 kg/ha in 1996, 1160 kg/ha in 2003, 1270 kg/ha in 2004, and 1210 kg/ha in 2006. In Safi, the high yields were 1620 kg/ha in 1994, 1410 kg/ha in 1996, 1550 kg/ha in 2004, and 1920 kg/ha in 2006.

The average yield of barley in Khouribga was 831 kg/ha and in Safi, 760 kg/ha. The low yields of barley in Khouribga were 390 kg/ha in 1992, 310 kg/ha in 1993, 330 kg/ha in 1995, 10 kg/ha in 2000, 40 kg/ha in 2001, 340 kg/ha in 2005, 10 kg/ha in 2007, and 260 kg/ha in 2008. Low yields of barley were obtained in Safi in 1992 (240 kg/ha), 1993 (400 kg/ha), 1995 (100 kg/ha), 2000 (320 kg/ha), 2001 (240 kg/ha), 2005 (390 kg/ha), 2007 (250 kg/ha), and 2008 (250 kg/ha).

The high yields of barley were obtained in 1988 (1440 kg/ha), 1989 (1460 kg/ha), 1994 (1450 kg/ha), 1996 (1800 kg/ha) and 2003 (1410 kg/ha) in Khouribga. For Safi, the high yields of were 1400 kg/ha in 1988, 1550 kg/ha in 1994, and 1460 kg/ ha in 1996.

Standardized precipitation index

Data analysis showed a high correlation (r = 0.67) between SPI-JM (January to March) and SPI-OJ (October to June). However, the relationship between SPI-AJ (April to June) and SPI-OJ was lower (r = 0.33). All the correlations between the other SPIs were not significant; the coefficients of correlation between SPI-OD (October to December) and SPI-JM was 0.01, between SPI-OD and SPI-AJ, 0.24, and between SPI-OD and SPI-OJ was 0.12. The correlation between SPI-JM and SPI-AJ was zero (r = 0).

To evaluate drought severity during the entire cereal growing season (October to June), we used the SPI-OJ (Table 1). SPIs with negative values were obtained in all regions, except those indicated between parentheses after the date, in 1992, 1993, 1995, 1999, 2000 (Safi), 2001 (Kenitra and Fes), 2002, 2005, 2007 (Fes), and 2008. The values for these listed 10 years are underlined and bold in Table 1.

Negative values were also registered in Khouribga in 1989 (-0.10), Fes in 1994 (-0.21), El Jadida (-0.28) and Safi (-0.15) in 1998.

The highest SPIs (more than + 1.00) were obtained in all regions in 1996, being +2.19 in El Jadida, +1.89 in Kenitra, +1.21 in Fes, +1.98 in Meknes, +2.26 in Khouribga, and +2.58 in Safi. High values were also registered in 1997 in El Jadida (+1.73), Kenitra (+1.14), Meknes (+1.01) and Khouribga. Other years were also very wet; among these are 1988 in Khouribga (+1.06) and Safi (+1.33), 1990 in Fes (+1.28) and Meknes (+1.47), 1994 in Khouribga (+1.04), 2003 in Kenitra (+1.47), 2004 in El Jadida (+1.3), Kenitra (+1.10) and Fes (+1.31), and 2006 in Fes (+1.34) and Meknes (+1.09).

Relationship between SPI and yield

The results of the regression analysis relating yield as a dependent variable to SPI-OD and SPI-AJ as independent variables showed that the values of R^2 were very low and the relationships were not significant. The observed variations of yields were explained mainly by the variations in SPI-JM and SPI-OJ.

Table 1. Variation in SPI-OJ in different regions from 1988 to 2008.

Year	Region with access to supplemental irrigation		Northern region under rainfed conditions		Southern region under rainfed conditions	
	El Jadida	Kenitra	Fes	Meknes	Khouribga	Safi
1988	0.71	0.51	0.31	0.66	1.06	1.33
1989	0.09	0.28	0.03	0.31	-0.1	0.56
1990	0.48	0.2	1.28	1.47	0.46	0.71
1991	0.32	0.6	0.91	0.74	0.52	0.35
1992*	**-0.99**	**-1.63**	**-0.54**	**-0.57**	**-1.06**	**-1.38**
1993*	**-1.17**	**-0.98**	**-0.85**	**-0.81**	**-0.7**	**-0.68**
1994	0.23	0.26	-0.21	0.27	1.04	0.18
1995*	**-2.22**	**-1.7**	**-2.46**	**-1.52**	**-0.76**	**-1.63**
1996	2.19	1.89	1.21	1.98	2.26	2.58
1997	1.73	1.14	0.6	1.01	1.75	0.95
1998	-0.28	0.85	0.23	0.56	0.3	-0.15
1999*	**-0.03**	**-0.86**	**-1.55**	**-1.54**	**-0.6**	**-0.82**
2000*	**-0.87**	**-0.72**	**-1.13**	**-0.98**	**-1**	0.02
2001*	**-0.53**	0.45	0.2	**-0.45**	**-0.74**	**-0.81**
2002*	**-0.35**	**-0.34**	**-0.65**	**-0.74**	**-0.21**	**-0.27**
2003	0.86	1.47	0.99	0.94	0.54	0.5
2004	1.3	1.1	1.31	0.38	0.3	0.83
2005*	**-0.95**	**-0.83**	**-0.89**	**-1.15**	**-0.96**	**-1.12**
2006	0.17	0.43	1.34	1.09	0.46	0.59
2007*	**-0.65**	**-1.24**	0.09	**-0.57**	**-1.66**	**-1.09**
2008*	**-0.06**	**-0.87**	**-0.2**	**-1.09**	**-1.16**	**-0.7**

* Years when drought was registered in all regions according to the SPI classification (negative numbers).

Table 2. Coefficients of determination (R^2) showing the relationship between grain yield of bread wheat and SPI at different time scales.

Region	SPI-OD	SPI-JM	SPI-AJ	SPI-OJ
El Jadida	0.05	0.36	0.04	0.48
Kenitra	0.00	0.20	0.00	0.34
Fes	0.00	0.51	0.01	0.62
Meknes	0.02	0.51	0.01	0.50
Khouribga	0.01	0.62	0.00	0.74
Safi	0.00	0.42	0.07	0.52

For bread wheat (Table 2) in the drier areas, the relationships between yield and SPI-JM were positive and significant. The value of R^2 was 0.62 for Khouribga and 0.42 for Safi. For SPI-OJ, the R^2 value was 0.74 for Khouribga and 0.52 for Safi. For Fes the R^2 value was 0.51 for Meknes 0.51, for El Jadida 0.36, and Kenitra 0.20 when the SPI-JM was considered. For SPI-OJ the R^2 value was 0.58 for Fes, 0.50 for Meknes, 0.58 for El Jadida, and 0.28 for Kenitra.

For durum wheat (Table 3), the R^2 value linking the yield and SPI-JM was 0.56 in Khouribga, 0.36 in Safi, 0.55 in Fes, 0.39 in Meknes, 0.30 in El Jadida, and 0.17 in Kenitra. For SPI-OJ, the coefficient of determination was 0.65 in Khouribga, 0.38 in Safi, 0.52 in Fes, 0.36 in Meknes, 0.40 in El Jadida, and 0.23 in Kenitra.

For barley (Table 4), similar results were observed. The R^2 value between yield and SPI-JM was 0.63 for Khouribga, 0.48 for Safi, 0.69 for Fes, 0.38 for Meknes, 0.43 for El Jadida, and 0.28 for Kenitra. In the case of SPI-OJ, it was 0.70 in Khouribga, 0.53 in Safi, 0.62 in Fes, 0.36 in Meknes, 0.45 in Al Jadida, and 0.27 in Kenitra.

Table 3. Coefficients of determination (R^2) showing the relationship between grain yield of durum wheat and SPI at different time scales.

Region	SPI-OD	SPI-JM	SPI-AJ	SPI-OJ
El Jadida	0.04	0.30	0.00	0.34
Kenitra	0.06	0.17	0.00	0.30
Fes	0.01	0.55	0.00	0.55
Meknes	0.00	0.39	0.00	0.39
Khouribga	0.01	0.56	0.00	0.65
Safi	0.01	0.36	0.10	0.44

Table 4. Coefficients of determination (R^2) showing the relationship between grain yield of barley and SPI at different time scales.

Region	SPI-OD	SPI-JM	SPI-AJ	SPI-OJ
El Jadida	0.00	0.43	0.09	0.42
Kenitra	0.00	0.28	0.01	0.28
Fes	0.00	0.69	0.01	0.60
Meknes	0.00	0.38	0.00	0.42
Khouribga	0.01	0.63	0.00	0.69
Safi	0.01	0.48	0.08	0.61

DISCUSSION

The cropping systems of Morocco are dominated by cereals, which are mainly grown under rainfed conditions. These are characterized by frequent droughts that limit production. In fact, data analysis showed that, during the last two decades, the average grain yields of all cereals were very low and the inter-annual variation was very high; productivity varied from 150 to 3000 kg/ha. Chafai et al. (2008) reported a wheat yield range for the whole country of Morocco from 500 to 1500 kg/ha, with a coefficient of variation of 40%, and regional and species differences. In Kenitra, yields tended to be higher than in El Jadida for bread wheat and barley. In respect of durum wheat, the difference between the two regions was not clear. The higher performance of cereals in Kenitra can be explained by the fact that this zone is located further north in the country where rainfall is usually higher. In Meknes, the yields of the three species were, in general, higher than in Fes. In the case of the drier regions, the yields were the highest in Safi for durum wheat and in Khouribga for barley. Khouribga is known for its barley production because of the importance of livestock production in the region and in Safi the farmers practice fallow, which conserves water for the following crop (usually wheat).

The yield gap analysis conducted on wheat in the rainfed areas of WANA (Pala et al., 2011) showed that the differences between the farmers' yields and those that are potentially achievable are high. This yield gap results from the inappropriate crop and land management practices used by most of the farmers, with some differences between wheat and barley. In the case of barley, the low levels of grain yields can be explained by the fact that this crop is usually grown in monoculture in marginal lands (shallow, degraded, saline, sandy soils, etc.) with minimum inputs (fertilizers, herbicides, etc.). These low levels of yields are also a result of growing old varieties or landraces that have low harvest indices. Nonetheless, with their high vegetative biomass production, they are the more preferred genotypes by farmers because they are used as forage for livestock. Wheat, however, receives relatively better management. This crop is usually grown after food legumes or fallow and benefits from the residual soil moisture and nitrogen. Moreover, the farmers, especially in more favorable areas, apply some fertilizers and use certified seeds and herbicides. The higher yield of wheat as compared to barley can be explained also by the higher genetic gain in wheat, as more varieties with better harvest indices have been released and are being used by farmers. Sanchez-Garcia et al. (2013) showed that in Spain from 1930 to 2000, the genetic gain in terms of yield in wheat was 0.88%.

In general, analysis of the data showed high inter-season grain yield variations and the trend followed that of the rainfall pattern. Low yield values were obtained for all species in 1992, 1993, 1995 (except for Al Jadida and Kenitra), 1999, 2000 and 2007, and in Meknes for bread wheat in 1993. Low yields were also registered in 1999 for all species in Fes and Meknes. In the particularly wet years of 1996 and 2006, high productivities were obtained.

In 1996 high yields were obtained everywhere for all crops, except in Fes and Meknes for all species. Also in 2006 high yields were obtained in all regions and for all species except for durum wheat and barley in Khouribga and for barley in Safi.

The yield levels obtained in each region are very much affected by the rainfall gradients that characterize Morocco. In the country, the average rainfall amount decreases from north to south and from west to east. Fes, Meknes, and Kenitra, Located in the northern part of the country, usually receive more rains and tend to produce greater yields. However, in the southern parts, such as Khouribga, El Jadida, and Safi, precipitation is lower, with Safi being the driest, and hence crops yields are less. Nevertheless, yields in Kenitra and El Jadida tended to be relatively high because these regions are located in irrigated areas and some fields may have received supplemental irrigation in dry years. Research conducted on the response of wheat to water applications (ICARDA, 2013) in the rainfed area of the Tadla region of Morocco showed that, on average, supplemental irrigation during spring increased wheat yield by around 20% and saved more than 1000 m^3 of irrigation water as compared to the farmers' flood irrigation technique.

The general feature of drought in Morocco before 1987 was demonstrated by studies of the Direction de la météorologie national (DMN, 1997). These studies showed that the country experienced 10 episodes of major moderate to severe droughts between 1900 and 1987. Moreover, Jlibene (2011) states that drought has become more frequent during the last three decades. It has increased from one dry year to 15 normal ones before 1980s to a frequency of one dry year to each three year period. However, this author does not specify the intensity of the drought. In our case, rainfall data analysis, using the meteorological drought index SPI-OJ, demonstrated that during the last two decades, all the regions studied experienced, on average, droughts with different intensities (SPI varying between -0.5 and -2.5) with a frequency of one year of drought for every 2.6 year period. The frequency of moderate to severe drought (SPI less than -1) as defined by Mckee et al. (1993) was, however, only one year of drought for each seven year period. In all regions, 1992 and 1995 tended to be the drier years. Other years were also very dry in some regions, such as 2000 in Fes and Khouribga and 2007 in Kenitra, Khouribga, and Safi.

Because whenever there is drought in Morocco it tends to be general, it is difficult to cope with this natural catastrophe in rainfed agriculture. In fact, cereal yields under these conditions are generally low and there is no possibility of compensation among regions in terms of production. Moreover, access to supplemental irrigation is very limited. Under these conditions, the common solution adopted by the State to meet the immediate needs of the population is to import commodities to fill the gaps. Unfortunately, relying on imports only is a crisis management approach which is very costly and poses the problem of some dependence on other countries. A potential solution to the low yields in Morocco arising from recurrent drought is the adoption of a risk management approach, such as taking more advantage of good (wet) years and producing more using appropriate agronomic packages. More production, however, means the development of more grains storage facilities.

Early warning of drought occurrence and the prediction of yields early during the cereal cropping season is one of the components of a drought preparedness approach. SPI is an index that can be used for this purpose. Our study showed that there is no correlation between SPIs computed for the stand establishment and grain filling periods of cereals. This result confirms that of El Mourid and Watts (1989) who did not find any link between autumn rainfall and that of spring. The only positive and significant correlations observed in our study are the ones that exist between the SPI-JM and SPI-OJ and between these indices and yield (high R^2). These results contradict the findings of Yacoubi et al. (1998) and Barakat and Handoufe (1998) who showed, in rainfed areas of Morocco, a strong relationship between the rainfall deficit index of October, November, and December and the cereal production deficit of the growing season.

The no correlation between yield and SPI-OD in our study can be explained by the fact that most of the farmers are waiting until it rains enough to be able to prepare a good seedbed and ensure a good germination of seeds and emergence of seedlings. They also usually increase the seed rate to compensate for low stand establishment under deficit soil moisture conditions following planting. The non-significant relationship between yield and SPI-AJ might result from the increase of carbon assimilates translocated from the stems and sheaths to the grains under drought conditions during spring. Reynolds et al. (2005) stated that reserves accumulated in the stem by anthesis may play a crucial role in grain filling under terminal stress conditions when photosynthesis is impaired.

The importance of rainfall or soil moisture conditions in the mid-season growth period can be explained by the fact that the most determinant yield components in cereals, the number of spikes and number of kernels, are formed during the January to March period. Consequently, any water stress during this period has a negative effect on the development and growth of tillers and spikes. Otegui and Slafer (2004) indicated that only a relatively small fraction of the whole growing period of cereals is actually critical to the determination of yield. This corresponds, in general, to the stem elongation period where the number of grains per unit land area is largely determined in response to the growing/partitioning conditions of the crops. The importance of the availability of moisture in the soil during the stem elongation period was confirmed by supplemental irrigation studies. Boutfirass (1990) demonstrated that supplemental irrigation during tillering-stem elongation increases wheat yield. Also Karrou and Boutfirass (2007) found that the availability of the soil moisture required for growth and development during the stem elongation period is a pre-requisite for wheat yield increase and stability in rainfed areas. Because of the relatively high correlation between SPI-JM and SPI-OJ and between SPI-JM and yield, the former index (SPI-JM) can provide an early prediction of the severity of the whole season drought and also the yields.

This index can be considered as a drought preparedness tool that can help the farmers better schedule and manage supplemental irrigation, fertilizers application and weed control, accordingly. The tool can be also used by policy-makers to better plan the allocation of water in agriculture, forage availability for the livestock safeguard, seed production, and wheat imports. Nevertheless, to better detect the development of droughts and monitor their intensity and duration, SPI should be used in coordination with other tools such as remote sensing (NDVI-based indices) to cover vast geographic regions; and this will further improve the timely predictions of drought onset that can trigger appropriate responses by the policymakers (Sarkar, 2011).

From this study, we can conclude that rainfall conditions during the tillering and stem elongation periods of cereal growths are the most important determinants of yield and, hence, the SPI computed for the period of January–March can be used to predict drought severity and yields early in the season.

Conflict of Interest

There are no conflict of interest regarding this publication.

ACKNOWLEDGEMENT

This work was supported financially by CGIAR Research programs, CRP - Climate change, Agriculture and Food Security and CRP – Dryland Systems.

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