Research Article

Wheat yield vulnerability: relation to rainfall and suggestions for adaptation

Khalid Tafoughalti[1,3*], E.M. El Faleh[1], Y. Moujahid[2], F. Ouargaga[1]

[1] Geology Department, Faculty of Sciences, Moulay Ismail University, Morocco
[2] Regional Center for Agricultural Research - URGDRNESR- Meknes, Morocco
[3] Chemistry Department, Faculty of Sciences, Moulay Ismail University, Morocco

*corresponding author: khalid.tafoughalt@gmail.com

Abstract : Wheat production is of paramount importance in the region of Meknes, which is mainly produced under rainfed conditions. It is the dominant cereal, the greater proportion being the soft type. During the past few decades, rainfall flaws have caused a number of cases of droughts. These flaws have seriously affecting wheat production. The main objective of this study is the assessment of rainfall variability at monthly, seasonal and annual scales and to determine their impact on wheat yields. To reduce this impact we suggested some mechanisms of adaptation. We used monthly rainfall records for three decades and wheat yields records of fifteen years. Rainfall variability is assessed utilizing the precipitation concentration index and the variation coefficient. The association between wheat yields and cumulative rainfall amounts of different scales was calculated based on a regression model to evaluate the impact of rainfall on wheat yields. Data analysis showed moderate seasonal and irregular annual rainfall distribution. Yields fluctuated from 210 to 4500 kg/ha with 52% of coefficient of variation. The correlation results show that soft wheat and hard wheat are strongly correlated with the period of January to March than with the whole growing-season. While they are adversely correlated with the mid-spring. This investigation concluded that synchronizing appropriate adaptation with the period of January to March was crucial to achieving success yield of wheat.

Keywords: adaptation mechanisms, drought, mid-spring, precipitation concentration index, wheat yield

Introduction

Morocco is especially notable for its vulnerability to climate change (Stocker, 2014), climate is characterized by long periods of drought and a strong interannual variability in rainfall amount and distribution (Sebbar et al., 2011, 2012; Karrou, 2014), that impose a wide range of direct and indirect impacts on crop production. In the past few decades Moroccan agriculture have been suffering from severe water resources deficits (Chbouki et al., 1995; Born et al., 2008; Sowers et al., 2011), then playing a significant role in crop growth and yield. Risks to agricultural production due to climate variations have been reported through various studies (Lobell and Field, 2007; Requier-Desjardins, 2008; Pala et al., 2011; Karrou, 2014). In Morocco, cereals represent the main crop and are of great importance to national food security; the main part of the diet comes directly or indirectly from cereals (FAO, 2006). There is why it is important to understanding the natural climate factor governing its development. Production levels are generally poor compared to other countries in the Mediterranean Basin (FAOStat, 2016). The heaviest bills are those of cereals, which represent almost 36% of imports in 2014 (MAPM, 2015). In earlier studies, Jarlan et al. (2014) has mentioned that the development of cereals is related to local environmental

conditions, among which water availability are the most decisive. This discovery is consistent with previous works (Jouve et Daoudi, 1984; Watts and El Mourid, 1988; Zeggaf et al., 2002). Rainfall furnishes the water which contributes to the transportation of the nutrients for plants development. In consideration of this essential role, deficiency of water supply, especially during critical developmental stages have negative effects on efficient plants growth, resulting enormous yield reductions. Meknes is among the provinces that contribute most to national wheat production. Considering that 97 percent of agriculture is non-irrigated, and since most of crops rely on adequate rainfall, this has translated to wide variations in yields and production. What might straightly is influencing the living of the inhabitants within this province. This study analyses rainfall variability at annual, seasonal and monthly scales and evaluate the correlation between rainfall and the yields of two major crops in Meknes province of Morocco. Additionally, it proposes some mechanisms of adaptation to reduce the risks of rainfall uncertainties and to reach good production of wheat.

Material and methods

Study area

The domain of study was Meknes province north-west of Morocco (Figure 1). It is situated between longitude 33°88 N and latitudes 5°53 S. It has an area of 1692 km^2. The area is characterized by a semi continental climate of Mediterranean type, with cool winters and rainy and hot summers and dry. The temperature means range from 3 °C in cool season and 34 °C in hot season.

Figure 1. Location of Meknes in Morocco

According to HCP, the High Commission for Planning, directorate of statistics (Haut-Commissariat au Plan, Direction de la Statistique, 2015), about 149000 persons live in countryside with rainfed agriculture as their primary source of income. 97% of arable lands are under rainfed system (Figure 2a). The most agricultural areas are used for non-intensive cereal production (soft wheat, hard wheat and barley). Figure 2b shows the crop types percent of total arable area during the last five years (2010 to 2015), where the cereals occupy 50% of the agricultural area, 21% to plantation crops, 14% to pulses, 6% to forage, 5% to vegetables, 2% to oilseeds, and 3% was fallow. Soft wheat is the major crop and the most widely cultivated cereal followed by hard wheat, barley and maize on a smaller significant scale. Considering the diversity of factors of soil formation and parent material, different types of soils exist of which calcareous and heavy soils predominate.
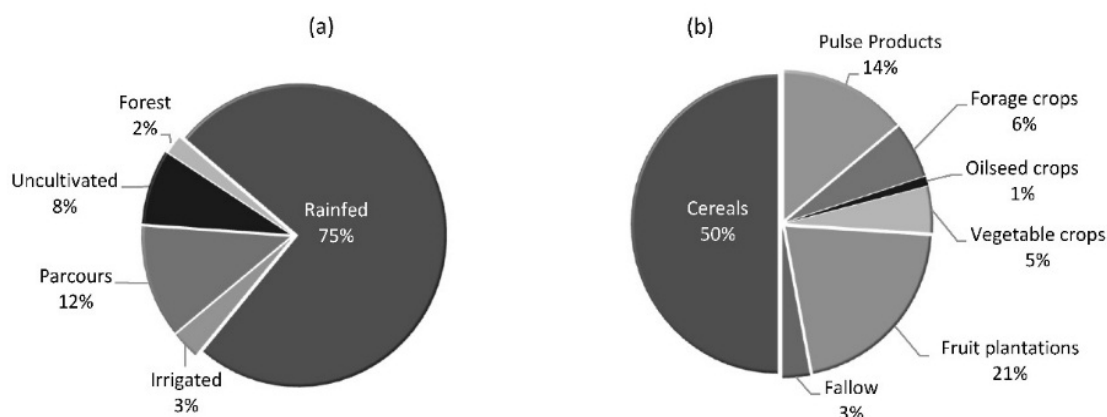

Figure 2. Use land percent of total area (a) and crop type's percent of total arable area (b) for Meknes

Most of these soils are relatively rich with very productive potential. The average annual rainfall ranges from 450 to 600 mm. The rainfall cycle is monomodal and start from September to May. Currently, plowing and sowing are programmed every year in Meknes between September and December while the harvest occurs between May and July. The key challenge to agriculture in Meknes province is insufficient rainfall.

Data and analysis methods

A rainfall data recorded over three decades (from 1985 to 2015) and crop yield records of soft wheat and hard wheat from 1995 to 2015 were provided by DPA; Department of Agriculture in the province of Meknes (Direction Provinciale de l'Agriculture de Meknes). The mean and Coefficient of Variation (CV), Standard Deviation (SD) of monthly, seasonal and annual rainfall are computed by using Excel software. The Precipitation Concentration Index (PCI, Oliver, 1980; Michiels et al., 1992) was calculated on an annual scale, and on growing-season scale from October to May through the following equations (1) and (2):

$$(1) \; PCI_{annual} = \frac{\sum_{i=1}^{12} pi^2}{\left(\sum_{i=1}^{12} pi\right)^2} \times 100$$

$$(2) \; PCI_{growing\text{-}season} = \frac{\sum_{i=1}^{8} pi^2}{\left(\sum_{i=1}^{8} pi\right)^2} \times 75$$

Where pi is the monthly precipitation in month i, PCIannual denotes twelve months, and PCIgrowing-season denotes eight months.

The precipitation concentration index was also calculated on a seasonal scale for winter (DJF), spring (MAM), autumn (SON), and on supra-seasonal scale for wet season (ONDJFM) using equations (3) and (4):

$$(3) \; PCI_{seasonal} = \frac{\sum_{i=1}^{3} pi^2}{\left(\sum_{i=1}^{3} pi\right)^2} \times 25$$

$$(4) \; PCI_{supra\text{-}seasonal} = \frac{\sum_{i=1}^{6} pi^2}{\left(\sum_{i=1}^{6} pi\right)^2} \times 50$$

According to Oliver's classification:
A PCI value of less than 10 represent a uniform precipitation distribution; PCI values from 11 to 15 denote a moderate precipitation concentration; values from 16 to 20 denote irregular distribution and values above 20 indicates a strong irregularity (i.e., high precipitation concentration). To evaluate the relationship between rainfall and wheat yields we used the correlation analysis. The calculation of the correlation coefficient is performed using Equation (5), in which rainfall represents the independent variable (X) and wheat yield represents the dependent variable (Y).

$$(5) \; r = \frac{\sum(x - \bar{x})\,(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2\,(y - \bar{y})^2}}$$

Where $\bar{x}$ and $\bar{y}$ are the mean of the matrix X and the matrix Y respectively.

Result and Discussion

Patterns of rainfall

The trend of the total annual rainfall (mm) from 1984-2015 in Meknes province is as shown in the Figure 3. The annual rainfall volume was variable from year to year and ranges from 284 mm to 876 mm. In seasons 2008-2009, 2009-2010 and 2012-2013 the annual rainfall amounts surpass 800 mm and fall below 300 mm in 1994-1995. For growing-season by using its precipitation median of 480 mm, the results show a highly unpredictable rainfall pattern from year to year and this is clearly presebted in the following graph (Figure 4).
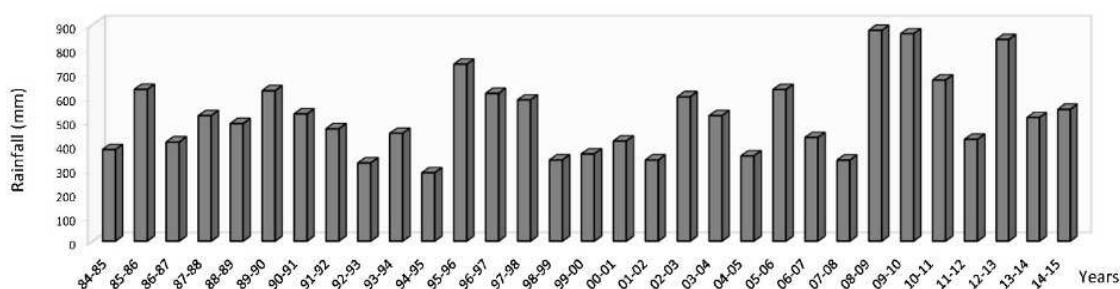

Figure 3. Annual rainfall in Meknes region during the seasons from 1984-1985 to 2014-2015

Also observed, ten years of over median, two years (1997-1998 and 2013-2014) of around median and eight years of beneath median. The monthly rainfall pattern as given in Figure 5 for the twenty-year growing season (October to May) varies markedly between and within seasons, from 306 mm in 1998-1999 and 1999-2000 to 793 mm in 2012-2013 seasons. From Table 1 one can learn that growing season account 93% of total annual rainfall where more than 46% occurs in winter-season and approximately 20% in the ending of autumn and 20% at the beginning of spring.
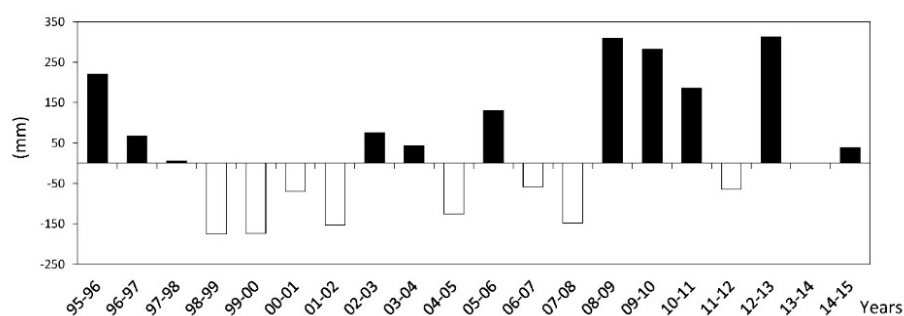

Figure 4. Pattern of Growing-season rainfall (October-May)
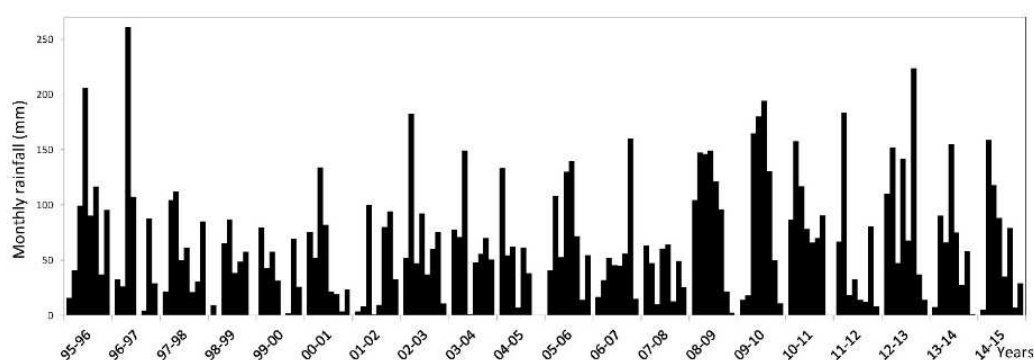

Figure 5. The growing season (October to May) monthly rainfall, Meknes, 1994-2015

Table 1. Descriptive statistics for rainfall of multiple time scales from 1984 to 2015

	Annual	Growing Season	Supra-Season	Autumn	Winter	Spring
Mean	520	486	405	145	221	142
Standard Deviation	159	148	155	72	112	60
Minimum	285	213	155	16	57	38
Maximum	876	793	765	335	539	275
Coefficient of Variation	31	30	38	50	51	42
PCI (%)	17	15	12	13	11	13
Total %	100	93	76	28	41	28

Wheat yield trends

Historical records of soft and hard wheat yield from 1995 to 2015 as represented in Figure 6 show that, in general, the yield is low and variable in time. The coefficient of variation was very high, showed 52% for soft wheat and 53% for hard wheat. The highest observed yield was approximately 4500 kg/ha for both hard and soft wheat, registered in season 2014-2015, while the lowest yields were 210 kg/ha for hard wheat and 240 kg/ha for soft wheat obtained in season 1999-2000, it was a very dry year. Such variation has often exposed poor farmers to migration to cities.
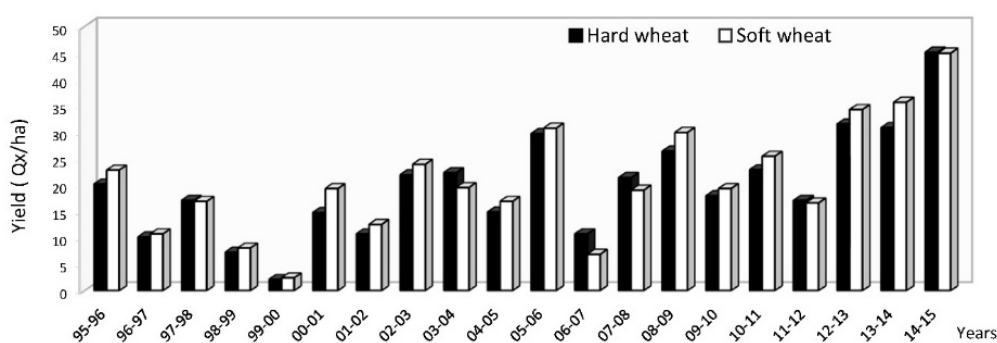
Figure 6. Variation of yield of hard wheat and soft wheat of Meknes from 1995 to 2015

Variability of rainfall and distribution

The rainfall variability resulted by coefficient of variations of seasonal and annual rainfalls have shown that there existed a moderate variability, except for autumn and winter seasons where rainfall variability is high. Standard Deviation shows 72mm for autumn and 112mm for winter (Table 1), such values can lead to a success or failure of the crops. Additionally, on yearly basis, the computed PCI annual value of 17% indicates that, rainfall distribution over months is erratic. Generally dry years have recorded a high values (PCI ranges from 15 to 25). Nonetheless, the PCI value for season indicates moderate rainfall concentration (PCI<13). Monthly average rainfall in Meknes is a clear seasonal cycle. Generally, most of the precipitation occurs between November and January. This situation often fills the soil profile of the coarse-textured soil. A preview of the monthly rainfall trend over the period of two decades shows that monthly rainfall amount tend to decline in February after reaching its peak in December and January. In respect to distribution Figure 7 show that rainfall in the month of February and March are very erratic; the variation coefficient showed respectively 78% and 87%. This might present dangers of water stress and dry spells which has a proven effect on yield since it coincide with production phase. This information suggests that the farmers should adopt irrigation technologies as a way to cope with situations of water shortage during the crucial phases of production.
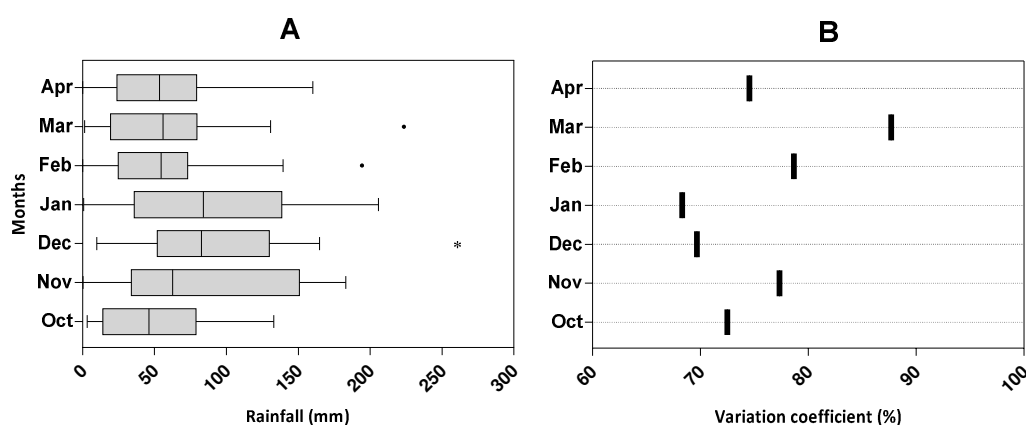

Figure 7. Box plot (A) and coefficient of variation (B) of monthly rainfall (Oct to Apr) from 1995 to 2016. Note: The boundary within the box marks the median.

Relationship between rainfall and wheat yield

The Table 2 shows the relationship between rainfall of different period and yield of hard and soft wheat. Whereby all results, for seasons and inter-seasons are positive and significant. For spring, the correlation coefficient values were low. It showed 0.22 for hard wheat and 0.15 for

soft wheat. Unfortunately, because the most rainfall of this season (March to May) coincides with wheat maturation. While a moderate amount of rainfall benefits wheat grain development, however, waterlogged soils during grain fill contribute to high disease pressure and can reduce wheat yields and test weight. In contrast, a strong correlation was illustrated between wheat yield and rainfall at the other intervals; the correlation coefficients range from 0.49 to 0.74 for hard wheat and range from 0.50 to 0.79 for soft wheat. Thus revealing that the beginning and the middle of growth period is the most sensitive stages of

growth to rainfall. Owing to the fact that the water supply from rainfall during this period will affect the root yield, the survival and fertilization of ears and consequently of the grains. The highest value of correlation was obtained between wheat yield and rainfall of January to March (JFM). They were 0.72 and 0.75 for hard and soft wheat respectively. These results reveal on the one hand the importance of rainfall volume of the period January to March, on the other hand the damaging effect of mid-spring rains. Both factors independently influence annual yield of soft and hard wheat.

Table 2. Coefficients of determination showing the relationship between wheat yield and rainfall at different time scales.

Crop/Time	Annual	Grow season	Supra-season	Autumn (SON)	Winter (DJF)	Spring (MAMy)	Inter-season			
							ONDJ	JFMA	JFM	FMA
Hard wheat	0.65	0.71	0.74	0.57	0.49	0.22	0.59	0.64	0.72	0.56
Soft wheat	0.67	0.73	0.79	0.58	0.55	0.15	0.65	0.65	0.75	0.50

Correlation between yield and rainfall of decisive months

The results of correlation analysis represented in Figure 8 show that the correlations relating yield to December and April rainfall are respectively negative and strongly negative. The average of correlation coefficient for both wheat was (-0.1) with December and (-0.4) with April. This

suggests April rainfall pattern has tendency to move in the contrary direction. When a high rainfall volume or a long period of raining can cause serious damage. This confirms the low correlation recorded above; between wheat yield and spring. Whereas the lower correlation with December may be attributed to the fact that water supply is minimal (beginning germination).
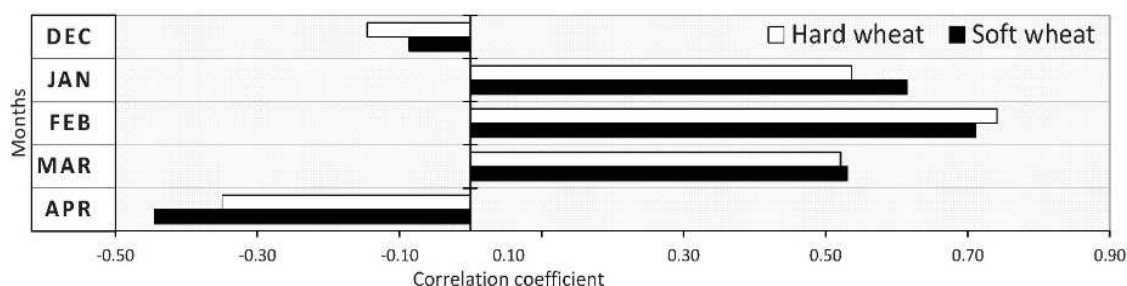

Figure 8. Correlation between wheat yield and rainfall of December, January, February, March and April

Also, as shown in Figure 8, the relationships between yield of both wheat and January, February and March rainfall were positive and significant. So it can be said that yield can be estimated from rainfall volume of January, February and March together. Despite the high rainfall volumes in January, compared with that of February, the value of coefficient of correlation for February was higher (0.7). This is due to the fact that February coincide with a period of very active plant growth phase (End of the tillering

stage and stem elongation stage). It follows as noted by Acevedo, 2002 that mild to moderate water deficits during this period will decrease cell growth and leaf area with a consequent decrease of photosynthesis per unit area. That will lead to a significant yield reduction. It is also pointed out that these interrelationships can be more reliable by introducing the number of the rainy days and particularly the duration between two successive bursts of rain. Prolonged dry days of two or more weeks can have a noticeable negative effect on

crop growth rate and development (Barron et al., 2003; Laux et al, 2008). Therefore, even if it is raining after, it makes very little difference because the damage is done. However, the result of correlation is statistically non significant, while it is substantively significant.

Adaptation mechanisms to rainfall variability

Considering all of the above, it is clear that January to March is the critical period to the determination of yield. Period of which the rainfall volume in every month must be over its median. As described in this study, the rainfall is highly variable with greater uncertainly. Therefore, the farmers are at high risk of crop failure. Below we suggest six points to minimize or mitigate the risks of these rainfall anomalies on crop of wheat and achieving yield success:

1. Research and developments of drought tolerant wheat varieties. Varieties which have short growth duration for escape of terminal drought stress, larger and deeper root systems that allow deep soil moisture extraction, and efficiency of water use.
2. Early warning and making correct decision to avoid the crisis by synchronized investigation in real time effects of rainfall volume on wheat production.
3. Reduced soil evaporation; according to Siddique et al. (1990) in Australia, under Mediterranean climate, up to 40% of the total available soil water is evaporated directly to the atmosphere without taking part in transpiration. Likewise, Passioura (2006) noted that the ecophysiological limits of crop yield in relation to water supply give a limit of about 20–22 kg of grain per millimeter of water transpired, at least with current cultivars and practices, and averaged over a whole season. Direct seedling or shading surface of soil by the crop canopy are crucial for reducing this water loss and therefore taking part in transpiration by capture via deep root system under drought stress (Mitchell et al., 1996; Kirkegaard et al., 2007).
4. Irrigation; as a measure for long term, within this circumstance of weather instability, the government should develop facilities of irrigation (economic irrigation) therefore the farmers might water crops during periods of rain shortage.
5. Land Management; as viewed in this study, wheat yield is often moderate in spite of good rainfall volume in some years. Therefore, farmers should improve their soil health which can help to put on fertilizers depending

to the need determined by fertility status of the soil. Poor fertile soil is a major constraint to sustainable agricultural productivity. One strategy for applying appropriate soil-conservation practices is to use green manure and bio-fertilizers.
6. Periodic training courses for farmers on improved, economic, modern technologies and practices, so farmers' level of awareness is often the foremost step for any agricultural success.

Conclusion

The study assesses the rainfall variability and its relationship with wheat yields in Meknes province of Morocco. It revealed moderate seasonal and irregular annual rainfall concentration. When the estimated correlation between wheat yield and rainfall at different scale showed a significant effect of the precipitation. It was concluded that wheat yield variability was correlated with rainfall variability under the current climate in Meknes. The yield variability showed a higher relationship with precipitation at small period (January to march) than at the larger period. Having these results, it is recommended that the farmers should not entirely depend on the rain fed agriculture since the rainfall patterns change in Meknes province, hence they must adopt appropriate mechanisms as using improved crop varieties that survive adverse climatic conditions, water-conservation practices, soil health improvement, but especially irrigation schemes to mitigate or minimize the adverse effects of water stress that occur in the crucial period (January to March) of production of wheat.

Acknowledgments

References

Acevedo, E., Silva, P. and Silva, H. 2002. Wheat growth and physiology. Bread Wheat. Improvement and Production. Food and Agriculture Organization of the United Nation. Rome, 39-70.

Barron, J., Rockström, J., Gichuki, F. and Hatibu, N. 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology* 117(1): 23-37.

Born, K., Fink, A. H. and Paeth, H. 2008. Dry and wet periods in the northwestern Maghreb for present

day and future climate conditions. *Meteorologische Zeitschrift* 17(5): 533-551.

Chbouki, N., Stockton, C.W. and Myers, D.E. 1995. Spatio-temporal patterns of drought in Morocco. *International Journal of Climatology* 15 (2): 187-205.

FAO. 2006. The State of Food and Agriculture 2006: Food Aid for Food Security? FAO, Rome.

FAOStat. 2016. FAOSTAT database collections. Food and Agriculture Organization of the United Nations. http://faostat.fao.org.

Jarlan, L., Abaoui, J., Duchemin, B., Ouldbba, A., Tourre, Y. M., Khabba, S., Le Page, M., Balaghi, R., Mokssit, A. and Chehbouni, G. 2014. Linkages between common wheat yields and climate in Morocco (1982–2008). *International Journal of Biometeorology* 58(7): 1489-1502.

Jouve, P. and Daoudi, A. 1984. Effets de la date de semis sur l'elaboration du rendement du blé tendre et de l'orge en zones semi-arides et arides (cas du Maroc atlantique). *L'agronomie Tropicale* 39(3) : 216-228.

Kirkegaard, J.A., Lilley, J.M., Howe, G.N. and Graham, J. M. 2007. Impact of subsoil water use on wheat yield. *Crop and Pasture Science* 58(4): 303-315.

Mitchell, J.H., Fukai, S. and Cooper, M. 1996. Influence of phenology on grain yield variation among barley cultivars grown under terminal drought. *Crop and Pasture Science* 47(5): 757-774.

Lobell, D.B. and Field, C.B. 2007. Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters* 2(1): 014002.

Laux, P., Kunstmann, H. and Bárdossy, A. 2008. Predicting the regional onset of the rainy season in West Africa. *International Journal of Climatology* 28(3) : 329-342.

MAPM, (Ed.). 2015. L'agriculture marocaine en chiffres 2014, Statistique du ministère de l'agriculture et de la pêche maritimes, Rabat.

Michiels, P., Gabriels, D. and Hartmann, R. 1992. Using the seasonal and temporal precipitation concentration index for characterizing the monthly rainfall distribution in Spain. *Catena* 19(1): 43-58.

Karrou, M. and Oweis, T. 2014. Assessment of the severity and impact of drought spells on rainfed cereals in Morocco. *African Journal of Agricultural Research* 9(49): 3519-3530.

Oliver, J. E. 1980. Monthly precipitation distribution: a comparative index. *The Professional Geographer* 32(3): 300-309.

Passioura, J. 2006. Increasing crop productivity when water is scarce -from breeding to field management. *Agricultural Water Management* 80(1): 176-196.

Pala, M., Oweis, T., Benli, B., De Pauw, E., El Mourid, M., Karrou, M., Jamal, M. and Zencirci, N. 2011. Assessment of wheat yield gap in the Mediterranean: case studies from Morocco, Syria and Turkey. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. iv, 963-21.

Requier-Desjardins, M. 2010. Impacts des changements climatiques sur l'agriculture au Maroc et en Tunisie et priorités d'adaptation. Centre International de Hautes Études Agronomiques Méditerranéennes, Montpellier.

Sebbar, A., Badri, W., Fougrach, H., Hsaine, M. and Saloui, A. 2011. Étude de la variabilité du régime pluviométrique au Maroc septentrional (1935-2004). *Science et Changements Planétaires/Sécheresse* 22(3) : 139-148.

Sebbar, A., Hsaine, M., Fougrach, H. and Badri, W. 2012. Étude des variations climatiques de la région centre du Maroc. Les climats régionaux: observation et modélisation, 709-714.

Siddique, K.H.M., Tennant, D., Perry, M.W. and Belford, R.K. 1990. Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. *Crop and Pasture Science* 41(3): 431-447.

Sowers, J., Vengosh, A. and Weinthal, E. 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change* 104(3): 599-627.

Watts, D. G. and El-Mourid, M. 1988. Rainfall patterns and probabilities in the semi-arid cereal production region of Morocco.

Zeggaf, T.A., Nsarellah, N., Hadrabach, D. and Baidani, A. 2002. Caractérisation de la variabilitéspatiale du climat marocain en relation avec la productivité des céréales à petites graines. *Rev. HTE* (124): 84-92.

Stocker, T. (Ed.). 2014. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.