

## **EFFECTS OF DROUGHT ON WINTER WHEAT YIELDS IN A SEMI-ARID REGION**

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### **Abstract**

The cultivation of wheat in arid regions is an economically risky undertaking, mainly of fluctuating rainfall distribution and alternative dry spells throughout the growing season. Statistical analysis previously carried out shows the rainfall season usually starts in December and ceases in April, the reason the wheat crop is planted during the month November/December and harvested during the month of June in the northern part of Algeria. Although the wheat is a relatively drought-resistant crop, it may be sensitive to the random effects of severe drought conditions. According to its occurrence during the cycle, drought may be decisive on the final production quantity and quality. This study is an attempt to estimate reductions in wheat yields caused by drought. Acting from soil-plant-atmosphere interactions, impact of water deficit on wheat yield can be estimated for each of the main growing stages. To lessen the effects of drought and maximize results, we adjusted better to the wheat growing season by selecting three useful sowing dates. A means of assessing the effects of drought on the yield of wheat is of considerable interest to agronomist in the prospect of climate change adaptation. The simulation was conducted in ten consecutive agricultural years (1989-1998), for three locations characterizing the semi-arid climate in north western Algeria, by using CROPWAT software which incorporates the distribution of rainfall over the growing season. The methods of calculating water needs of crops are mainly based on methods presented in the FAO bulletins of irrigation and drainage. The analysis of obtained results in semi-arid Mediterranean, particularly in the north-western Algeria, show that the total seasonal rainfall is insufficient to cover the water requirements of rainfed crops, especially winter cereals. On the other hand, the rainfall distribution over time favors during the development cycle, the occurrence of periods of water stress periods which the final yield. However, planting date suitably chosen provides, to some extent a more interesting biological itinerary, which subtracts the plant in such a climate hazard and dampens the reducing effects of drought.

**Keywords:** Wheat yields, Rainfed Crop, Drought, CROPWAT software

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### **INTRODUCTION**

The cultivation of winter wheat is mainly rainfed, particularly on the south shore of the Mediterranean. It is subject to variable rainfall patterns and often low which result in periods of drought control. This water often stressful environment imposes a limit to the expression of genetic abilities cultivars and partly explains the stagnation of performance that has not improved significantly in over a century. Indeed, as an example for the wilaya of Saida, the average annual return for the period 1871-1875 is similar to that of 1991-1995, is 6 to 8 quintals per hectare (Benseddik and Benabdelli, 2000). Periods of recurring droughts recorded in recent years in Algeria, (Aberrahmani et al., 2006) and the weak performance of crop's yield that resulted confirm the random nature of precipitation (Hassini et al., 2008) and incentives to better identify the water stress. The water stress is poorly defined when we reason at the level of phenomenological changes that occur in the body (show leaves, tillering, flowering ...) or even cell for physiological traits (water content, sweat ...) (Bruns and Cory, 1983). Daily rainfall appears to be best suited to characterize and identify the influence of this parameter on the phases of growth and development of wheat and thus better manage performance (Fisher, 1973). In order to study the influence of planting date on the different phenological stages of wheat we chose three planting dates and achieve a simulation of the behavior of culture with free FAO software CROPWAT. CROPWAT is a software program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. This program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. All calculation procedures used in CROPWAT are based on the two FAO publications of the Irrigation and Drainage Series, namely, N°56 "Crop Evapotranspiration - Guidelines for computing crop water requirements" (Allen et al, 1998) and N°33 titled "Yield response to water" (Doorenbos and Plusje, 1979).

## MATERIAL AND METHODS

In this study, we used the CROPWAT software which incorporates the distribution of rainfall over the growing season and the deficit of water relative to potential needs. The analysis is based on three experimental sites representative of grain semi arid region in West Algeria, located at 35° Northern Latitude. Their main characters are described as follow:

- **Oran:** climatic zone located in north west Algeria (Greenwich longitude 0° 37' W, latitude 35° 45' N) and characterized by a dry Mediterranean climate.

- **Sidi Bel Abbes:** located in west of Algeria (Greenwich longitude 0° 38' W, latitude 35° 15' N) and characterized by a semi-arid climate.

- **Tiaret:** located in south west Algeria (Greenwich longitude 1° 19' E, latitude 35° 19' N) and characterized by a sub Saharan climate.

These three zones present similarities: the rainy season lasts 150 days per year and presents the same temporal rainfall distribution. Meanwhile Tiaret's rainy season begins earlier and has an irregular rainfall distribution over time.

The meteorological parameters used are:

- Temperature: Maximum, minimum and average temperatures data in degrees Celsius were used.

- Humidity: Relative moisture expressed in percentage or vapor pressure in kPa.

- Daily sunshine: Percentage ratio of sunshine / day length or sunshine hours.

- Wind speed: The averages daily course of wind measured 24 hours in km/day or m/s.

More elaborated parameters like real evapotranspiration and consumptive water use are estimated.

In relation to crop models it is very common and useful to notice that all kinds of crop yields reflect different environmental and management conditions in which these different crop yields would be obtained.

To study the impact of climate in one or other kind of yield and simulate the influence of one or other condition upon final, we use a set of definitions as follows:

• **Potential yields  $Y_p$**  are obtainable yields in actual temperature and solar radiation conditions. All the rest of requirements are totally satisfied. They are genetical, temperature and radiation limited yields. Usually obtainable only in carefully designed experimental conditions at laboratories and agricultural research institutions. Soil conditions specifications are absolutely unnecessary because water and nutrients are automatically assigned by model algorithms without taking real soil parameters into account.

• **Real yields  $Y_a$**  are obtainable yields in actual temperature, solar radiation and precipitation conditions without any irrigation, the rest of requirements are totally satisfied. They are genetical, temperature, radiation and water limited yields. In particular, because similar periods without water caused different degrees of plant water stress at different stages of development, crop yield results reflect the interaction of these two factors. In this study, such a case is simulated by considering three different planting dates that coincide with December the 5<sup>th</sup>, 15<sup>th</sup> and 25<sup>th</sup> for all the sites. These dates are selected in relation with the beginning of rainy season derived from climatic data analysis. The simulation is carried out by using the "CROPWAT" software which incorporates the distribution of rainfall over the growing season and the deficit of water relative to potential needs.

The main equation which expresses the yield response to water is given below:

$$(1 - Y_a / Y_p) = K_y (1 - ETR / ETM)$$

Where  $Y_a$  and  $Y_p$  are the same parameters as mentioned above

ETR: real evapotranspiration

ETM: maximum evapotranspiration

These three zones present similarities: the rainy season lasts 150 days per year and presents the same temporal rainfall distribution. Meanwhile Tiaret's rainy season begins earlier and has an irregular rainfall distribution over time.

A simplified notation of phenological phases of wheat adopted as follows:

Phase A: Tillering.

Phase B: Stem Extension.

Phase C: Heading.

Phase D: maturity.

This is consistent with the rating Feekes' and Zadoks' scales (Alley et al., 2009). It should be noted that among the scales quantifying the development of cereal crops currently used, Feekes and Zadoks scales are most common (Figure 1).

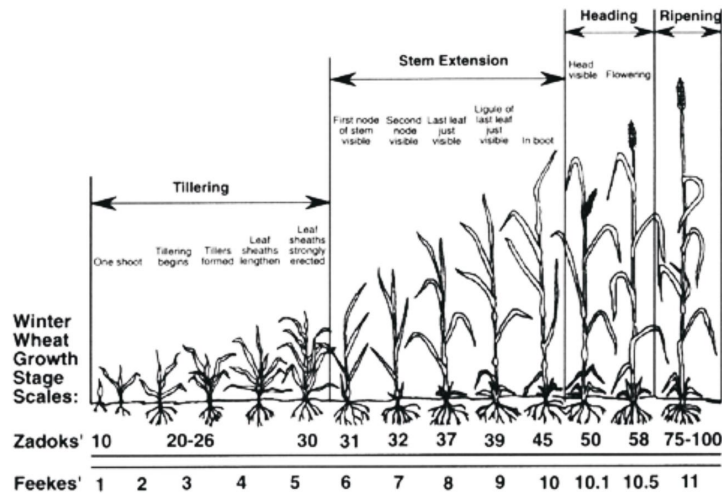


Figure 1: Growth stages of wheat according to the Zadoks and Feekes scales (Alley et al., 2009).

## RESULTS AND DISCUSSION

In general, the amount of rain, collected during the agricultural year, covers consumption needs of water at up to 55%. The water deficit that results may also involve one or more phases, the sensitivity will be decisive in the final production. For winter wheat, the first phases of the growing season are somewhat protected from the vagaries of the weather by selecting a suitable planting date and the fact that they coincide with the rainy season. Meanwhile, the other phases suffer the effects of drought more or less severe. The magnitude of these effects depends on the stage of development. The results show that heading and maturity stages are more sensitive to water stress. A lack of water during these two periods will drastically reduce yields. The reduction is expressed here as a percentage of the potential yield.

Table 1: yield reduction (in %) due to each development stage in the first zone

Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	21,9	38,3	26,2	Planting date: December 5th
1990	0	0	9,8	34,3	17,6	
1991	0	0	21,3	37,1	25,5	
1992	0	0	16,3	28,7	19	
1993	0	0	30,7	37,9	31,1	
1994	0	0,1	36,1	39,5	35,4	
1995	0	0	25,7	36	26,8	
1996	0	0	22,5	38,3	26,3	
1997	0	0	31,5	38,9	33	
1998	0	0	31,6	37,7	31,6	
Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	15	36,3	21,5	Planting date: December 15th
1990	0	0	5,4	30,3	13,8	
1991	0	0	15,1	33,8	20,7	
1992	0	0	14,6	22	16,2	
1993	0	0	27	36,4	28	
1994	0	0	32,5	39	33,3	
1995	0	0	19,8	34,3	22,8	
1996	0	0	16,5	36,6	22,3	
1997	0	0	27,1	37,7	30,4	
1998	0	0	26,4	35	28,1	
Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	28,5	39,2	30,1	Planting date: December 25th
1990	0	0	16,2	37	22	
1991	0	0	27	38,6	29,6	
1992	0	0	19,1	33,5	21,7	
1993	0	0	33,9	38,7	32,6	
1994	0	0,8	39,7	39,7	37,3	
1995	0	0	31,1	37,6	30,3	
1996	0	0	28,2	38,9	29,7	
1997	0	0	35,9	39,3	35,2	
1998	0	3,4	36,1	38,9	34,7	

Table 1 indicates the yield reduction as a response due to a drought occurring during the main stages of development in the first location. In Mediterranean climate, the first part of the development cycle such as phases A and B that include the period from sowing to flowering, have no visible negative impact on wheat performance (Table 1).

The weighted effect of all the water stress during all the entire biological cycle is calculated under “**agricultural season**” column for the three planting dates simulated. It shows that the drought is commonly observed and a sowing on middle December would limit its negative effects on wheat production.

However, with the last planting date (25/12) showed that Phase B shows a yield reduction of 3.4% in 1998, accumulating a low total rainfall of 186 mm.

There is also in phase C for the year 1990 a minimum yield reduction regardless of the date of planting; this is due to sufficient rainfall. On the other hand, the maximum yield reduction at the same phase averaged 36.1% for 1994 due to weak distribution of rainfall over time. A water deficit occurs in late stage (Phase D) does not induce a high variability in yields. However, late planting exposes the plant to a high water deficit in ripening step in reducing the yield of nearly 40%.

In summary, in order to limit the risk of yield loss due to water stress, it is recommended early planting, or failing to make a supplemental irrigation during times of fertilization and fruiting (Table 2).

**Table 2: Seasonal rainfall (in mm) during the growing season and yield reduction (in %) according to planting date in Oran**

Planting date	December 5th		December 15th		December 25 th		Annual rainfall (mm)
	Seasonal Rainfall (mm)	Yield Reduction per agri.season (%)	Seasonal Rainfall (mm)	Yield Reduction per agri.season (%)	seasonal Rainfall (mm)	Yield Reduction per agri.season (%)	
1989	234.8	21.5	221.9	26.2	207.5	31.1	272.4
1990	329.3	13.8	321.7	17.6	312.1	22.0	457.3
1991	284.0	20.7	279.7	25.5	274.2	29.6	351.0
1992	272.8	16.2	267.8	19.0	262.3	21.7	340.3
1993	168.5	28.8	164.8	31.1	164.9	32.6	306.5
1994	141.2	33.3	138.0	35.4	133.8	37.3	227.9
1995	340.0	22.8	293.5	26.8	247.3	30.3	402.0
1996	322.5	22.3	312.4	26.3	298.0	29.7	368.6
1997	164.4	30.4	157.5	33.0	148.4	35.2	279.4
1998	162.7	28.1	148.8	31.6	133.5	34.7	186.1
Means	242.0	21.6	230.6	27.2	218.2	30.4	319.2

Sidi Bel Abbes's Station (*semi-arid climate*)

The rains occur usually in winter and enjoy the early development stages and ensure a smooth start of the crop. Thus the phases A and B do not suffer from water stress, did not significantly affect the level of production, with the exception of 1997 when the wheat crop has received only a small amount of water (141 mm of 323 mm needed) and unevenly distributed in time so that only 12 mm of rain are actually used by the plant during Phase B, hence the relative contribution of this phase to a lower yield (Table 3).

Inputs of rainwater (43 mm) in beginning of the stage C were insufficient to replenish the soil up to the reserve easily usable (84 mm) or even below the survival reserve (around 56 mm). This deficit has reduced the yield of 37%. Moreover, still in phase C, there is a minimal reduction in yield in 1990 and 1996 due to good rainfall annually, 408 mm and 477 mm respectively, which have limited the risk of occurrence of dry spells. Note that according to *C. Baldy* any water deficit occurring at the end of the cycle (phase D) is not limiting production if the soil moisture reserves are not exhausted. Nevertheless, high values of yield reduction due to a lack of water in D phase can be observed for irrigated crops more vulnerable to water stress than rainfed crops whose root growth is a form of adaptation to local variations of soil moisture. However, this resistance on a rainfed drought is only effective to the extent that a large proportion of rainfall occurs during its growth cycle. Table 4 below lists the contributions of rain during the growing season for agriculture each year according to the three planting dates selected and indicates that early planting is strongly recommended, but a supplemental irrigation is still needed in phase B from the agricultural year promises to be deficient.

**Table 3: yield reduction in % by phonological period in Sidi Bel Abbes region**

Year	Phase A	Phase B	Phase C	Phase D	agricultural season
1989	0	0	13,6	32,1	19,2
1990	0	0	6,4	27,6	13,1
1991	0	0	12,4	31,3	19,4
1992	0	0	12,3	22,4	15,1
1993	0	0	10	31,5	16,6
1994	0	0	23,1	38,2	28
1995	0	0	18,2	37,5	23,3
1996	0	0	6,3	16,7	9,5
1997	0	2,2	33,5	37,2	34
1998	0	0	27,8	36,6	30,5

Planting date:

December 5th

Year	Phase A	Phase B	Phase C	Phase D	agricultural season
1989	0	0	18,7	34,5	23,2
1990	0	0	9,9	32,1	16,7
1991	0	0	19,4	34,6	24,8
1992	0	0	14,5	28,5	18,3
1993	0	0	14,1	35,4	20,2
1994	0	0,1	28,3	38,4	31,3
1995	0	0	24,6	38,8	27,8
1996	0	0	10,2	20,2	13
1997	0	4,6	36,7	38,4	36,7
1998	0	0,3	32,7	38,6	33,9

Planting date:  
December 15th

Year	Phase A	Phase B	Phase C	Phase D	agricultural season
1989	0	0	23,5	36,8	27
1990	0	0	13,9	34,8	19,8
1991	0	0	25,7	37	29,3
1992	0	0	17,5	33,4	21,6
1993	0	0	18,5	37,5	23,4
1994	0	0,8	32,8	37,6	33,7
1995	0	0	30,2	39,4	31,6
1996	0	0	13,4	24,2	16,2
1997	0	6,4	39,9	39,1	38,9
1998	0	2,3	37,2	39,5	36,9

Planting date:  
December 25th

**Table 4: Total rainfall during the growing season and yield reduction vs. year according to the planting date in Sidi Bel Abbes**

Planting date	05/12		15/12		25/12		Total Rainfall (mm)
	Total Rainfall (mm)	Yield Reduction per season (%)	Total Rainfall (mm)	Yield Reduction per season (%)	Total Rainfall (mm)	Yield Reduction per season (%)	
1989	205.0	19.2	196.0	23.2	187.7	27	285.8
1990	299.5	13.1	285.9	16.7	268.4	19.8	408.3
1991	235.0	19.4	231.2	24.8	226.3	29.3	306.1
1992	245.9	15.1	240.9	18.3	235.4	21.6	281.6
1993	237.7	16.6	232.9	20.2	230.8	23.4	335.6
1994	175.4	28.0	175.4	31.3	173.8	33.7	301.9
1995	224.2	23.3	208.7	27.8	193.2	31.6	285.4
1996	411.0	9.5	415.4	13.0	412.9	16.2	477.3
1997	132.3	34.0	123.7	36.7	116.2	38.9	322.7
1998	155.2	30.7	144.3	33.9	133.2	36.9	186.5
Means	232.1	20.9	225.4	24.6	217.8	27.8	319.1

Tiaret's Station (*sub Saharan climate*)

Regardless of planting date, a maximum reduction of yield due to water stress for the two phases C and D, was observed in 1994. Both phases have received respectively 26 and 9 mm. Indeed, the proportion of

rainfall (115 mm) fell during the growing season has been far from sufficient to cover the needs estimated at 459 mm.

**Table 5: Percentage of yield reduction by phonological period in Tiaret region**

Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	16,7	23,3	18,2	Planting date: December 5th
1990	0	0	14,9	19,3	15,8	
1991	0	0	3,6	15,1	7,3	
1992	0	0	9,7	12,8	10,7	
1993	0	0	14,9	17,8	16,2	
1994	0	0	29,3	36,4	32,8	
1995	0	0	10,3	33,2	19,5	
1996	0	0	0,5	11,6	4,2	
1997	0	0	0,5	12,7	5,1	
1998	0	0	11,6	10,3	10,7	

Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	19,7	27,7	21,6	Planting date: December 15th
1990	0	0	17	23,3	19	
1991	0	0	6,4	24,4	13	
1992	0	0	11,2	20,1	14	
1993	0	0	18	26,5	21,2	
1994	0	0	33	38,2	35,7	
1995	0	0,2	16,7	33,8	23,2	
1996	0	0	3,6	20,4	9,4	
1997	0	0	1	24,9	11	
1998	0	0	11,1	22,6	15,7	

Year	Phase A	Phase B	Phase C	Phase D	agricultural season	
1989	0	0	14,7	18,1	14,9	Planting date: December 25th
1990	0	0	12,4	15,5	12,8	
1991	0	0	2	8,9	4	
1992	0	0	8,1	10,3	8,7	
1993	0	0	11,7	11,9	12	
1994	0	0	25	33,5	28,9	
1995	0	0	4,7	28,8	14,8	
1996	0	0	0	0	0	
1997	0	0	1,8	0	1	
1998	0	0	12,1	5,8	9,5	

The year 1996 for its part, had a relatively large rainfall (458 mm) and evenly distributed throughout the growing season, especially if it starts earlier (Table 6). Late sowing seems to be favorable to wheat production. Meanwhile, due to the relatively wide fluctuations in annual rainfall, large rainfall value is not always sufficient in itself to reduce the risk of occurrence of dry spells that may occur during the agricultural year. This is the case for the rainiest year 1997, particularly wet (543 mm), but much of the rain fell outside the growing season and the rest evenly divided over it. Thus drought occurring late in the cycle has reduced the yield of about 13 to 25% (late planting).

**Table 6: Total rainfall during the growing season and yield reduction according to the planting date in Tiaret region**

Planting date	December 5 th		December 15 th		December 25 th		Annual Rainfall (mm)
	Rainfall during growing season (mm)	Yield Reduction per season (%)	Rainfall during growing season (mm)	Yield Reduction per season (%)	Rainfall during growing season (mm)	Yield Reduction per season (%)	
1989	199.7	14.9	198.3	18.2	194.4	21.6	293.1
1990	251.3	12.8	252.3	15.8	248.6	19.0	326.8
1991	261.0	4.0	258.8	7.3	258.4	13.0	382.0
1992	251.1	8.7	249.9	10.7	245.3	14.0	303.0
1993	207.5	12.0	198.8	16.2	188.8	21.2	267.6
1994	114.7	28.9	108.9	32.8	107.3	35.7	334.3
1995	217.2	14.8	218.5	19.5	218.4	23.2	292.0

1996	372.1	0	378.7	4.2	384.1	9.4	458.0
1997	351.4	1.0	314.6	5.1	277.4	11.0	543.0
1998	226.7	9.5	225.5	10.7	222.1	15.7	253.0
Means	245.3	10.7	240.4	14.0	234.5	18.4	345.3

In spite of the relatively wide fluctuations in annual rainfall which range from 253 mm to 543 mm in the sampling period, the yield production seems to be largely dependent of rainfall, the other limiting factors such as temperature, disease or insect damage are not considered.

These results may however suggest that, in low-rainfall areas, goods results can be obtained by correlating reduction yields with water satisfaction needs.

## CONCLUSION

The results obtained in semi-arid Mediterranean, particularly in the north-western Algeria; show mainly that the total seasonal rainfall is insufficient to cover the water requirements of rainfed crops, especially winter cereals. On the other hand, the rainfall distribution over time favors during the development cycle, the occurrence of more or less periods of water stress that may affect the final yield.

Under semi-arid climatic conditions, it seems that the most critical rainfall period is from heading to the maturity. So, an earlier planting date provides, to some extent a favorable biological development, which subtracts the plant in such a climate hazard and dampens the effects of reducing drought.

## REFERENCES

- Abderrahmani b, Abbou M., Dobbi A. and N. Hassini, 2006. Evénements climatiques : caractérisation de la Sécheresse dans la Région d'Oran. In Actes du XIX<sup>ème</sup> Colloque de l'Association Internationale de Climatologie. Epernay (France), 6-9 septembre 2006. pp: 37-42.
- Allen R.G., Pereira L.S., Raes D. and M. Smith, 1998. Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and Drainage Papers no. 56. FAO, Rome (Italy).
- Alley M. M., Scharf P. Brann D. E., Baethgen W. E. and J. L. Hammons, 2009. Nitrogen Management for Winter Wheat: Principles and Recommendations. Virginia Polytechnic Institute and State University, publication 424-026.
- Benseddik B. and K. Benabdelli, 2000. Impact of climatic risk on durum wheat (*Triticum durum* Desf.) yields in semi arid regions. An ecophysiological approach. Science et changements planétaires / Sécheresse, 11(1): 45-51.
- Bruns, H.A. and L.I. Croy, 1983. Key developmental stages of winter wheat - *Triticum aestivum*. Economic botany, 37(4): 410-417.
- Doorenbos J., Kassam A.H., Bentvelsen C.L.M., Branscheid V. and Plusje, J.M.G.A., 1979. Yield response to water. FAO Irrigation and Drainage Paper no. 33, FAO, Rome (Italy).
- Fisher R.A., 1973. The effect of water stress at various stages of development in yield processes in wheat. In: Plant response to climatic factors. Proceeding Uppsala Symposium. Paris, UNESCO. 1973, pp 233-241
- Hassini N., Dobbi A., Bouchama M. and Abderrahmani B., 2008. Tendence et régionalisation des précipitations en Algérie : entre sécheresse et pluies diluviennes. In : Actes du XXI<sup>ème</sup> Colloque de l'Association Internationale de Climatologie, Montpellier (France), 9-13 septembre 2008. pp 321-326.