Comparative Review of the Most Important Weather Parameters and their Impact on Cotton Yield under Greek Conditions

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ABSTRACT

Important weather parameters and their impact on cotton productivity were investigated in three main regions of Greek cotton production. Daily values of air temperature, solar radiation and precipitation for the period 1994-1997 were used, recorded on data loggers in fully automatic meteorological stations installed in the three study areas. The total global radiation data were transformed to sunshine duration in hours. Crop development was assessed with the accumulated heat units method above a threshold temperature (10°C). It was found that the year-to-year fluctuations in cotton productivity could be estimated with this method, but only at a given area with similar management practice. Additionally, sharp drops in temperature during critical stages of cotton growth may result in appreciable reduction in crop productivity, even if the actual air temperature does not fall below the threshold levels for cotton growth.

Introduction

Cotton is one of the most important high input crops in Greece. The average seedcotton yield of over 2.7 t/ha, ranks among the highest in the world. Efforts to increase cotton yields during the last 10 day have been unsuccessful but great fluctuations have been observed, suggesting that Greece lies close to the northern limit for cotton production. Particularly adverse conditions prevailed in late 1996 when yields dropped by more than 1 t/ha in many areas. Farmers remember the total crop failure in Thessaloniki in 1976 (Chlichlias *et al.*, 1977).

Any study of the causes of these yield fluctuation should focus on the effect of weather conditions on cotton growth and development (Brooking, 1997). Solar radiation and temperature are of particular importance, determining the biophysical production potential (Mutsaers, 1982). The available period for growth is also very important, especially in areas near the northern border of the cotton belt, where the weather conditions during the beginning and the end of the growing period are often less than favorable for boll development and maturation (Galanopoulou, 1997). The main limiting factor is low temperatures that often prevail from the sowing period through the initial development, as well as low temperatures occasionally occurring during boll maturation and harvest, accentuating the importance of an early cotton stand. Apart from low temperature, excess spring rainfall may delay field preparation and sowing and induce root diseases, while excessive rain during boll maturation may negatively affect boll quality and impede harvesting (Galanopoulou, 1997). The available growing period is commonly expressed with the growing degree-days above a threshold temperature (Mauney, 1966; Ifoulis and Fasoulas, 1978; Danalatos, 1993). In consideration of these factors, a comparative review of the most important weather conditions such as rainfall, solar radiation and air temperature are presented and their impact on cotton productivity is investigated in three main Greek cotton regions, in the period 1994-1997.

Materials and Methods

Daily data on air temperature (°C), total global radiation (W/m^2) and rainfall (mm) were recorded during the period 1994-1997 in three automatic meteorological stations installed in the experimental farms of: a) the Higher Technological School of Thessaloniki, b) the Hellenic Cotton Board in Palamas (Karditsa), and c) the University of Thessaly (Velestino, Magnesia). As a more comprehensive measure of radiation, the sunshine duration (in hours per 10 day) was considered, using the simplified Angstroem formula (1924) and the variables introduced by Frere and Popov (1979) for Greek conditions:

$$SD = DAYL\,(day) * \frac{\frac{AVRAD}{DSO} - 0.20}{0.56} * 10$$

where SD is the sunshine hours per 10 day; DAYL is the maximum sunshine hours prevailing at 40° northern latitude for the given day of the year; AVRAD is the measured total global radiation (W/m^2) per 10 day, and DSO is the total incoming solar radiation (W/m^2) in the earth's atmosphere.

The average cotton yields in the Prefectures of Magnesia, Karditsa and Thessaloniki in the period 1994-1997 were used, taken from the official records of the Hellenic Cotton Board. A general appraisal of crop development was made based on the accumulated heat units, assuming a threshold temperature of 10°C. The phenological stages considered were sowing, 50% and 100%emergence, flower initiation and crop maturation, as recorded in field experiments in the study areas in the frame of the GOSSYM Project (AIR3-CT93-0936), which can be considered as representative of the study areas and years. For simplicity, the 10-day intervals during which these stages occur on average were recorded for the studied cultivars Zeta-2, Acala SJ-2, Korina and Sindos-80. The calculation of growing degree-days commenced at 50% emergence rather than the sowing date. This is considered advantageous since the sowing-emergence period is largely depended on the very variable soil moisture regime in addition to temperature.

Results and discussion

Temperature and phenological stages

Velestino: In 1994 and 1995, favourable weather conditions permitted the sowing in the second ten days of April, 50% emergence 10 days later, and full emergence in the first ten days of May. Flowering started from the third ten days of June (1995) to the first ten days of July (1994). An fairly constant sum was required in the period 50% emergence-flowering initiation (Table 2). Later in the season, the air temperature generally fluctuated slightly below average except for the warm year of 1994 (Fig. 1a). In 1996 and 1997, low spring temperatures postponed and crop emergence by 10 – 20 days. Later in June (1996), air temperature increased to reach or even exceed the average (28°C) during the end of the month, to drop again by 2°C below the average in mid-July (25°C) and remain at this level until the end of July, when flowering started.

Palamas was characterized by generally lower than average temperatures in the study years. In 1995, spring temperatures allowed sowing in mid-April, 50% and 100% crop emergence at the end of April and the first ten days of May, respectively.

In 1996, 50% emergence was recorded in the first ten days of May. There was a noticeable drop in temperature from >26°C to about 22°C during flowering initiation in early July 1996. These low temperatures prevailed until the end of July (Fig. 1b), i.e. for the greatest part of the flowering period. This probably delayed flowering, boll development and maturation. Low spring temperatures in 1997 resulted in late sowing and 50% emergence in mid-May. Later in the season, temperatures increased, speeding up crop development (Fig. 1b, Table 1).

Thessaloniki was generally characterized by lower than average air temperatures, especially in 1996 and 1997 (Fig 1c and Table 2). In 1995, the crop was sown in the second ten days of April and 50% and 100% emergence were recorded after 20 and 30 days, respectively. In 1996, 50% emergence was recorded in the second ten days of May. Despite the lower temperatures in Thessaloniki compared to Velestino in 1995, flower initiation was in the third ten days of June 1995 and first ten days of July 1996.

Sunshine duration

The total sunshine duration from May to August was similar in Palamas and Thessaloniki in 1994 through 1997 (Table 3). Velestino was generally more sunny especially in 1994 and 1995. The adverse year 1996 did not lack sunshine; contrarily, it was an even sunnier year for Palamas and Thessaloniki than the other study years. Finally, rather cloudy June and August 1997 made it the darkest year (Table 2).

The bright sunshine in July-August (effective flowering and boll development period for cotton) is particularly related to the amount of assimilates allocated to the storage organs. In 1996, sunshine duration ranged from 709 h in Velestino to 689 h in Palamas (Table 2), close to the average values while 1997 was the cloudiest year.

It should be mentioned that a negative relation between sunshine duration and productivity was found in Thessaloniki in 1976 (Chlichlias *et al.*, 1977). This was by far the darkest year in the last two 10 days, when total sunshine hours reached only 1037 h in Thessaloniki or 24 equivalent sunny days less than in the cool year 1996. During the boll development period in 1976, sunshine duration reached only 567 h, e.g. 126 h (or 9 equivalent bright days) less than 1996 (Table 2).

Rainfall

The available rainfall data gave no evidence of a negative effect of rainfall on early sowing and development of the crop, and thus on its proper maturation and harvest during the study years (Fig. 1). The exception was excessive rains and flooding in the third ten days of September 1994, which however only affected the very late stands. The adverse year 1996 was rather dry for all study sites, making the role of irrigation management on crop performance even more important.

Crop yields

The average yield in Magnesia in 1996 was only slightly lower than the yields in 1995 and 1994 (3.1 and 1.5 t/ha, respectively; Table 4). In the other two areas, however, there was a significant drop in yield in 1996 that could not be explained by difference in rainfall or radiation and so must have been due to prevailing temperatures and the length of the growing period for development and maturation. A slight positive correlation between yield (Table 4) and accumulated heat units (Table 2) can, in fact, be observed. However, in Karditsa and Thessaloniki, the yield-drop in 1996 of 1.1 t/ha was associated with a decrease in heat units by 100-120$_o$C-days. The same drop in heat units was associated with a much smaller yield decrease in Magnesia from 3.06 to 2.75 t/ha in 1996 and 1995, respectively (Table 3).

Apparently there is a threshold value of growing degree-days that makes the growing period long enough for boll maturation, so that any heat units above this critical value do not have any further affect cotton-yield. This is also the reason that the greater sum of heat units Magnesia in 1994 of 2200$_o$C-days, giving yields of 2.9 t/ha did not give higher yields than the 2100$_o$C-days, giving 3.06 t/ha in 1995. Furthermore, the critical value does not seem to be invariable for all circumstances. For example in Thessaloniki, 1720$_o$C-days were enough for a very good yield in 1995 (3.35 t/ha), whereas a yields dropped by 410 kg/ha in Karditsa (2.94 t/ha) under 1840$_o$C-days. This cannot be explained by temperature alone. It is strongly believed that the management of the crop is adapted to the average weather conditions prevailing in a given region. As mentioned, Palamas (Karditsa) is characterized by higher summer air-temperatures than those in Velestino. This results in a certain crop management to counterbalance the effects of high temperatures, e.g. shorter irrigation intervals, higher irrigation depths, higher plant populations, etc., so that the actual temperature in the leaf canopy of the crop remains at the optimum levels. Thus, a sharp drop in temperature by 5$_o$C for 20 days, as occurred in Karditsa in July 1996, does not allow the farmers to adapt their management to the change in conditions and leads to extended vegetative growth, delayed crop development and unfavourable results.

The drop in air temperature in the first 3 weeks of July 1996 probably played a major role in crop performance. In Karditsa, this temperature drop was too sharp and pronounced and, besides its negative effect on the crop growing cycle, it apparently exhibited a negative effect on flowering as temperature remained rather low for the season values (22$_o$C, Fig. 1b). The temperature drop in Magnesia did not bring about drastic differences. On the one hand this drop was not too sharp and on the other, because the air temperature did not drop much below the climatic average, remaining well above 24.5$_o$C during the critical period of flower initiation (Fig. 1a). The drop in air temperature in July was not so sharp in Thessaloniki. The good yield in 1997 despite rather low temperatures but in the absence of any sharp change in temperature or sunshine duration (Fig. 1c and Table 2) should be noted.

Conclusions

Low spring temperatures such as those prevailing in Greece in 1996, may delay crop sowing by 1-3 weeks, resulting in a delayed vegetative growth, boll development and maturation. Moreover, a sharp decrease in temperature may enhance large yield reduction, even if the temperature does not fall below critical levels for crop growth, probably due to the short time available for crop management adaptation to the new conditions and eventually resulting in an uncontrolled delay in crop development. This is probably the reason why the accumulated heat unit method for estimating crop development and productivity seems reasonable in countries as Greece, but only for regions with similar crop management lying near the northern border of the cotton belt. Further research is needed.

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Table 1. Accumulated heat units from 50% emergence (E) to flower initiation (F) and to end of October (M) in the various areas and years under study.

Year	Velestino		Palamas		Thessaloniki	
	E-F	E-M	E-F	E-M	E-F	E-M
1994	850	2,300	nd	nd	nd	nd
1995	850	2,200	660	1,840	610	1,720
1996	900	2,100	740	1,740	600	1,600
1997	860	2,050	Nd	1,890	Nd	1,560

(nd=no data available)

Table 2. Monthly sunshine hours measured in the study areas in the period 1994-1997.

Month	Velestino				Palamas				Thessaloniki				
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997	1976[1]
May	327	352	297	338	319	336	290	329	328	318	293	327	230
June	415	397	396	337	385	399	398	329	350	383	389	310	240
July	380	369	373	360	349	335	369	343	340	332	366	338	306
August	341	314	336	307	335	283	320	291	314	299	327	292	261
Total	1463	1432	1402	1342	1388	1353	1377	1292	1332	1332	1375	1267	1037
Jul+Aug	721	683	709	667	684	618	689	634	654	631	693	630	567

[1] Chlichlias *et al.*, 1977

Table 3. Seedcotton yield (g/m^2) recorded in the study areas during the period 1994-97.

Year	Magnesia	Karditsa	Thessaloniki
1994	290	317	318
1995	306	294	335
1996	275	185	225
1997	310	255	306

Figure 1. Temperature and precipitation in the study areas during the period 1994-97 (10-day intervals). The climatic (long-term average) values per month are included.