COTTON CROP MANAGEMENT UNDER MEDITERRANEAN CONDITIONS: USE OF WATER, N, PIX AND PLASTIC MULCH FOR EARLY PRODUCTION

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Abstract

Mediterranean conditions in the south of France that involve low temperatures and a short season limit cotton production potential. Potential duration, expressed as total degree-days (DD) (13°C basis) never exceeds 1400 DD, which is very low compared to most cotton production areas. Therefore, cotton production in this region requires the utilization of early season varieties and specific agronomic practices to get acceptable yields. Reported here are 1996 experimental results on the effects of plastic mulch, water management, nitrogen fertilization (N), and Pix® on phenology and blooming rate of a conventional, early-mid cotton variety (cv. DES 119-20). Twice weekly observations of blooms at the 1st position on sympodial branches allowed us to determine vertical flowering curves. Comparisons among plots for times of 1st bloom (DD), last bloom (DD) and the number of 1st position flowers per DD (slope of the curve) were accomplished by one-way analysis of variance (AOV). Compared to rain fed only plots, irrigated plots (with rainfall) significantly increased the last blooming node on the main stem, the total time (DD) elapsed to the last blooming node and the slope (i.e., rate of blooming). On irrigated plots, higher specific leaf N content due to the application of 120 kg N/ha increased the slope and significantly affected the last main stem node that bloomed in comparison with plants from unfertilized plots. Plastic mulch significantly decreased the time (DD) to 1st bloom, but had no effect on the slope and the duration of flowering. In addition to shortening the blooming, Pix® drastically decreased the slope of the blooming curve while watered with irrigation and supplemental natural rainfall. An inverse relation between the slope of the blooming curve and the time until cutout also indicates that further research should be done to optimize bloom duration and the number of fruiting sites plants establish under various conditions of water management.

Introduction

Cotton is an indeterminate, perennial crop so that, in theory, if temperature, water and mineral supply remain sufficient the plant continues to grow and establish new blooming sites. In practice, the characteristics of growth depend on genetic factors that interact with crop conditions. However, the literature indicates much variation in earliness due to genetic factors alone (Munro, 1971). Therefore, variability in crop duration of up to 40 days could be observed between early and late varieties grown under the same conditions. In addition to these genetic factors, agronomic practices and environmental conditions greatly influence crop duration as well. The physiological responses of cotton to water and N supply are well known. Jordan (1986) reports that water supply is the most effective edaphic factor on vegetative growth and crop duration. Radin and Mauney (1986) showed that an excess of nitrogen increased the vegetative development and crop duration. Well documented are the effects of crop regulators on crop duration and harvest preparation (Kerby, 1985).

In the south of France, the Mediterranean climate limits cotton crop duration due to lower temperatures and a short season. Fig. 1 illustrates the trend in mean daily temperatures from April to October (for 1996 and for a twenty year mean response) compared with a single year (1996) for a Mississippi location (i.e., Mississippi State). In both situations, spring and autumn cold temperatures limit the crop duration. But in France, the potential duration expressed in DD summation (13°C basis) never exceeds 1400 DD, which is very low compared to most other cotton producing areas. Therefore, for France, specific practices should be applied to get acceptable yields. In Spain, a common practice adopted from horticulture is to sow cotton under a plastic mulch during low temperature conditions in the spring (Marquez, 1990). However, plastic mulch is an expensive practice compared to the potential yield that can be obtained if short season conditions also are present. Therefore, we assume that, as observed on other indeterminate crops (Thomson, 1997), water restriction could also be used as a practice to reduce climatic risks and improve farmer income, but at a lower cost of production than if plastic mulch were used.

Analyzing the components that would lessen the days between planting and harvest, Munro (1971) examined the date of the first flower (DFF), the node at which the first fruiting branch appears (NFB), the vertical flowering interval between two 1st position flowers on sympodias (VFI) and the horizontal flowering interval between two successive flowers on a fruiting branch (HFI). Likewise, Hesketh et al. (1972) showed a constant ratio between VFI and HFI. Therefore, we selected VFI in addition to NFB, DFF, the node of the last flower (NLF) and the date of the last flower (DLF) as components that characterize earliness. Reported here are the effect of plastic mulch, water and N supply and Pix on a conventional early-mid variety (cv. DES 119-20).

Two areas of application or focus are: (1) to develop a well-described data set for use in simulation model calibration, verification and validation, and (2) to learn more about relationships of selected agronomic practices to develop better management tactics in cool, and/or dry, cotton production areas found in less developed countries of the Third World.

Material and Methods

Experimental Design and Data Collection

The experiment was conducted at the CIRAD experimental center of Montpellier (42°60' North and 3°90' East) in 1996. On deep loamy soil, 5 plots were sown on 5/7/1996. Each plot consisted of 10 rows, 12 meters in length in a conventional 0.8 x 0.1 m plant population design. Table 1 indicates the experimental treatments along with symbols and plot numbers (as assigned at Montpellier) that are used to reference, or describe, the treatments.

Irrigation consisted of a 130 mm supply, applied from emergence to mid-bloom (by sprinklers). Nitrogen fertilization (pearl urea) consisted of either 0 (0N) or 30 kg N/ha applied at sowing only (30N) and 60 kgN/ha applied at sowing + 30 kgN/ha at 1st bloom + 30 kgN/ha at mid-bloom (120N). Soil analyses completed before sowing revealed the presence of 110 kgN/ha (NO_3 + NH_4) in the 0-0.8 m horizon. Plastic mulching was mechanically placed, by adding a plastic application device to the sower. Pix® was applied 1.5l kg/ha on 6/20 and 7/12.

Soil temperature

Plastic mulch warms the soil in order to accelerate plant development. In addition to plant attributes, we measured soil temperatures at 5 and 45 cm depths over time. Measurements were collected during the three weeks after mulch application for both the mulched plots and bare soil plots at the same level of irrigation.

Soil Water Availability

Soil water content was measured weekly with a neutronic probe, for each 0.2 m increment to a 2.5 m depth. The fraction of transpirable soil water

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:346-351 (2001)
National Cotton Council, Memphis TN

(FTSW) was thus calculated using root growth kinetic, soil water content and soil hydraulic characteristics (Sinclair and Ludow, 1986). These authors also showed a high relationship between FTSW and foliar potential for a given soil, so that FTSW provides information on plant water status. A FTSW value of 1 corresponds to soil water saturation. If FTSW is between 1 and 0.7, then plants can be considered to be well watered. On loamy soils, plant growth rates decrease for FTSW values less than 0.6 – 0.7 and water stress occurs at 0.3 and lower.

Plant N Content

Dry matter production, leaf area index (LAI) and total leaf N% were measured on ten plants/plot at squaring, first bloom and cutout. The Specific Leaf N content (SLN) was thus calculated as g N / m^2 leaf area, in order to characterize the plant N status (Sinclair and Horie, 1989).

Plant Phenology and Statistical Analyses

White flowers in first position on sympodias were noted twice a week from at most ten plants in each plot where the plastic mulch was not employed. For plots that employed the plastic mulch, at most twenty plants were measured at each observation. These plants were randomly chosen in each plot at the start of the observation period; thus, the study is a repeated measures experiment in a completely random design. Due to mortality, sample sizes were not equal over each observation (or time) period.

The data, when expressed in main stem node number vs. DD (by plot), appears on a graph as a succession of segmented lines corresponding to the different plants (Fig. 2). Considering each plant as an experimental unit, the replication of numerous plants in each plot allowed a statistical analysis of the results. The first result shown here is the linear shape of the blooming curves, that comes from a constant vertical flower interval (VFI; i.e., the time between two successive flowers at the first position on sympodial branches). A linear sympodial blooming curve allows paired comparisons (after analysis of variance (AOV)) among plots for the number of flowers appearing per DD (i.e., slope) (Fig. 3). In addition, the DFF, NFB, NLF, and the DLF can also be analyzed by analysis of variance (AOV).

The measured components were first transformed to ranks in ascending order. Transformation procedures are often utilized to stabilize variances (Mead, 1988), but that type of purpose was not appropriate for these data. Instead the rank transform was necessary due to small sample sizes available for some plots and the frequent occurrence of integer data having small magnitudes (e.g., close to zero). Therefore, most plant attributes were analyzed by a one-way AOV using the rank transform procedure (Conover and Iman, 1981) to determine differences among the five plots used in this investigation. The rank transform procedure has been found useful for insect sample data (Willers et al., 1999) which has many similarities to plant phenological data.

The PROC MIXED procedure (Littell et al., 1996) without specification of any random effects (e.g., use of the REPEATED or RANDOM statement) first provided a test of the hypothesis that the ranked variates among the five plots are all from the same random distribution. If the test statistic was significant (i.e., at least the ranks from one plot are different from ranks of the other plots), all possible pairwise comparisons (10 = (((5)(5-1))/2) of the differences between adjusted mean pairs was accomplished. This was done using the PDIFF option with the LSMEANS statement within the SAS® procedural statements. These pairwise comparisons determined which plots differed from one another for each attribute. No adjustments (e.g., Bonferroni or Sidak, etc.) for controlling the experiment-wise error rate was necessary since all pairwise comparisons of interest were planned *a priori*.

The PROC MIXED procedure has also been employed with these data to perform an analysis using a repeated measures design (Littell et al., 1996). Only a limited part of this type of analysis is reported herein. Due to the unequal sample sizes among the plots and unequal sample sizes that occurs with time (e.g., day-degrees (13°C), i.e., dd_13c below), the analysis has been subjective and required an ‘artful creativity’ to complete an analysis. The most difficult task has been the determination of which form to employ for modeling (Littell et al., 1996) the covariance structure. The following code fragment best summarizes the iterative modeling process as well as the final model syntax in SAS®:

```
proc mixed data=b;
Title 'This is the final model that includes an intercept and gives interesting comparisons.';
class plot plant time;
parms .82 1.38 1.57 1.87 .77;
model fb=plot dd_13c plot*dd_13c/ddfm=kr solution;
repeated time/subject=plant(plot) type=ARh(1) r;
lsmeans plot/at dd_13c=550 pdiff;
lsmeans plot/at dd_13c=650 pdiff;
lsmeans plot/at dd_13c=750 pdiff;
lsmeans plot/at dd_13c=850 pdiff;
lsmeans plot/at dd_13c=950 pdiff;
run;
```

The iterative portion involved the selection of a model for the different covariance structures by replacing different options in the TYPE statement above. Several forms (See Littel et al., 1996) were tried, i.e., compound symmetry (CS), unstructured (UN), first-order autocorrelation (AR (1)), and heterogeneous (ARH (1)). The final choice was judged most appropriate. The PARAMETER statement also had to be used to provide starting values (see above). The starting values were obtained by trial and error by examination of the R matrix during iterative attempts at building a model. This is a common practice in fitting a statistical model to a complex data set. The effect, time, in the above model was added from a SAS® data step that created this variable. This variable is used to collate the sparse numbers across the actual observation times (i.e., dd_13c) into 4 classes 100 DD in width so there are more observations per interval. Accomplishing this step improved the ability of the SAS® software to converge to a final solution.

The repeated measures analysis allows for the comparison of differences among the plots at specific times of interest to the analyst (e.g., 550, 650, 750, 850, or 950 DD). The analysis also provides for the eventual comparison of the data at these various treatments (e.g., the plots) to output from a stochastic simulation model on cotton growth configured to the agronomic practices, soil types and weather conditions of the plots utilized in this field experiment.

Results

Differences among the plots could be due to relationships between agronomic practices (e.g., nitrogen fertilization, irrigation, plastic mulch and Pix®) and the environment. Described first are the results that evaluate the effects of different practices and environment on earliness.

Plant Water and N Status and Soil Temperature

Fig. 4 shows the 5 plots FTSW trends over time (expressed in DD units above 13 °C). From emergence until 220 DD, there is no difference among the plots, because plants in all plots have adequate water in soil reserves. After 220 DD, the curves start to separate as a result of some plots (Nos. 1, 2, 12 and 13) receiving irrigation. Rain-fed plants (Plot 25) were submitted to a water stress (or WS) less than 0.3 FTSW between about 400 to 700 DD. This interval is about 100 DD before first bloom and just prior to mid-bloom. Irrigation maintained plants in moderate water stress (0.3 < FTSW < 0.6) between 500 to 900 DD, which corresponds to the blooming period (or MWS). After 900 DD, all plots declined below 0.4 FTSW.

The evolution of the specific leaf N (SLN) content (g N / m² leaf area) against physiological time exhibits two groupings of plots (Fig. 5). Due to a weak vegetative development, plants obtained from the unfertilized rain fed plot (Plot 25) and the 30 kg/ha Pix® (with irrigation) plot (Plot 2) present the same high SLN (or HSLN) values as those from the 60+30+30N (with irrigation) plot (Plot 12). On the other hand, the 0 (Plot 13) and 30kgN/ha with plastic (Plot 1) that were also irrigated plots portrayed low SLN (or LSLN) values.

Fig. 6 shows the daily trends of mean (water saturated) soil temperatures at 5 and 45 cm depths in relation to air temperature. Seedling horizon (at 5 cm) temperature varies closely with air temperature. However, depending upon air temperature, the addition of plastic mulch increases the seedling horizon temperature from 3 to 6 °C. The soil temperature at a depth of 45 cm has a slower response to air temperature variations. Compared to bare soil, plastic also influenced variation in deep soil temperature as quickly as eight days after application where a stable difference of 2°C could be observed at 45 cm depths. Therefore, plastic can be expected to effect plant growth since the physiological mechanisms are directly effected by temperature.

Phenology and Blooming Rate

Despite the highly unbalanced design of this experiment it has great utility as an exploratory (or screening) experiment (Haaland and Latour, 1994), in which the results of an analysis guide later experiments that are confirmatory or used to optimize a system. Comparisons were made as much as possible, between 'homologous' plots (i.e., two plots differing in only one level of the combination of soil temperature (heated by plastic mulch or not), plant water status (water stress or moderate water stress), plant N status (low or high SLN) and Pix (applied or not) with the other three levels held the same).

Treatments induced significant differences among all measured attributes. Mean values and statistical results are shown in Table 2. Each particular combination of practices corresponds to a plot (as numbered).

The effect of water on plant developmental progress can be seen on bare soil at a high SLN level, in comparison between water stressed plot 25 and moderate water stressed plot 12. Among these plots, irrigation significantly increased NLF (last flowering node), DLF (date of last flowering) and the slope (flowering rate).

The effect of nitrogen is observed on bare soil and water restricted plots, by making a comparison between plot 12 (high SLN) and plot13 (low SLN). Despite the lack of effect on DLF, the application of 120 kg N/ha increased the slope and significantly affected the NLF (last flowering node).

The effect of plastic mulch is revealed by comparison of plot 1 with plot 13 on bare soil, under moderate water stress and low SLN. Plastic significantly decreased the DFF (date of first flower) and NFB (first flowering node), had no effect on slope. Effect of plastic can be considered to induce a simple 100 DD shift in the blooming curve. The overall effect of the plastic mulch appears to decrease the time (in DD) from sowing to the first bloom and lowers the node number at which that flower appears (Table 2). During the blooming period, since the air temperature is high enough and the canopy shades the plastic on the ground, it is reasonable to find little effect of the plastic mulch on the slope. This unequivocal effect of plastic is suggested by overlap in levels of significance among the plots for differences in slope (see Table 2).

There is no homologous plot to directly evaluate the Pix® effect without plastic mulch. However, considering the absence of an effect of plastic on the slope (the non-significance between Plot 1 and 2 (Table 2)), a comparison can be done under moderate water stressed and high SLN between bare soil plot 12 and plastic mulch plot 2. For the results found here, the Pix® application drastically decreases the slope. Plot 2 has a slope, less than, but not significantly different from the water stress plot 25. Plastic mulch (Plot 2), when compared with Plot 1, which is watered and also has a plastic mulch, and whose slope is also equivalent to that of Plot 25, probably suggests that it is the Pix® and not the plastic mulch that slowed the flowering rate in Plot 2. This plot has the smallest flowering rate of all plots. Taken as a whole, these data suggest that to describe the relationship among water management, plastic mulch, and both nitrogen and Pix® would require a carefully planned future experiment.

Statistical Comparisons Among Plots by Time

Table 3 readily shows that the blooming rate over time (i.e., mainstem node) varies among the plots (i.e., treatments) and at different physiological times. The significance of the interaction term (dd_13c*plot) implies that a comparison among the plots for node number of the first position bloom needs to be accomplished for each time of interest.

Using the SAS® system, LSMEANS statements can be utilized to easily portray paired comparisons of predicted node number of the first position bloom at selected physiological times. Tables 4 and 5 show illustrative comparisons for times 550 and 950 DD. These types of output based on experimental plot data of the kind analyzed here would have tremendous value for the validation or verification of a stochastic model of cotton growth. Such comparisons are steps that will be performed in future work.

Care needs to be exercised, however, in the interpretation of the data similar to that of Tables 4 and 5. Extrapolation beyond the range of data observed is easily done with a statistical model of a data set. For example, plot 25 does not develop any mainstem nodes as high as those in plots 1, 2, 12, and 13 at 950 DD due to the lack of water. The LSMEANS statement will provide a predicted estimate of the node number for plot 25 at 950 DD that is past the node number actually observed.

Conclusion

The intent of the study was to accomplish a preliminary investigation on the effects of diverse practices (water, nitrogen, plastic mulch, and Pix®) and a Mediterranean climate upon plant status and phenology. Nitrogen status (SLN) was found to be dependent on both N fertilization and irrigation practices. As expected from the literature on the subject, plastic mulch altered DFF and supplemental irrigation influenced blooming duration. But, along with the effect of irrigation, nitrogen also had a slight effect on duration of blooming. On the other hand, it was unexpected to find different effects due to nitrogen, water and Pix® on the slope describing the sympodial nodes, first position blooming rate. The results, as a whole, show the potential for different combinations of agronomic practices to influence plant phenology. The total number of 1st position fruiting sites initiated for a given blooming duration can also be influenced. Knowing the boll position on the plant, as well as both boll weight and fiber quality, impacts on yield and quality can also be anticipated (Bradow et al. 1997).

The strong influence of water management on crop duration has potential for being a low cost production tactic with a reduction of risk. Thus, if water management can be well controlled by both the time and amounts of its application, the use of Pix® to control plant development may not be necessary. When plant development can be managed, or controlled, the amount of nitrogen needed to make a crop can be reduced, lowering costs of production even more (particularly in Third World production systems). However, interference due to uncontrolled rainfalls and the lack of an ability to monitor water availability in less developed parts of the world make the development of a complete management scheme along these lines of reasoning difficult. The inverse relationship between the blooming curve slope and an early cutout for both the water stress and Pix® plots reveals that a balance needs to be found in order to develop correct recommendations for farmers.

Acknowledgements

We appreciate the excellent assistance of Debbie Boykin, Biometrician, USDA-REE-ARS-MSA-OD, Stoneville, MS with the development of the repeated measures analysis procedures.

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Table 1. Experimental treatments.

	Bare soil (Bs)		Plastic mulch (Pl)	
Rainfall	0N plot n° 25	N/A	N/A	N/A
Rainfall + Irrigation	0N plot n° 13	120N plot n° 12	30N plot n° 1	30N + Pix plot n° 2

Table 2. Effect of practices and plant status on plant phenology.

Plot	Status	NFB	DFF	NLF	DLF	Slope 10^{-2}
n° 25	WS HSLN	6.38 b	583 b	11.50 a	796 a	2.526 a
n° 13	MWS LSLN	6.33 b	602 b	13.78 c	891 c	2.587 ab
n° 12	MWS HSLN	6.00 ab	598 b	15.71 d	932 c	2.957 b
n° 1	MWS LSLN	5.71 a	508 a	14.06 cd	835 b	2.604 ab
n° 2	MWS HSLN	5.78 ab	532 a	12.72 b	827 b	2.386 a

[1]Means within a column followed by the same letter are not significant at the P=0.05 level of probability.

Table 3. Type 3 Tests (Little et al., 1996) of fixed effects for a repeated Measures model for rate of flowering (determined by the node number of a first position bloom at anthesis).

Effect	Num DF	Den DF	F value	Pr > F
plot	4	111	5.07	0.001
DD_13C*plot	1	97	1880.77	<.0001
DD-13C*plot	4	93	3.76	0.007

Table 4. Differences (±SE) and significance levels of Least Squares Means for paired plot comparisons at 550 DD.

Plots	Estimate	St error	DF	T Value	Pr > | t |
1-2	0.4153	0.2584	37.5	1.61	0.1164
1-12	2.1079	0.4188	66.4	5.03	<.0001
1-13	1.2449	0.4702	90.2	2.65	0.01
1-25	1.0236	0.3447	42.8	2.97	0.005
2-12	1.6926	0.4243	65.5	3.99	0
2-13	0.8296	0.4751	89	1.75	0.0842
2-25	0.6083	0.3513	42.6	1.73	0.0906
12-13	-0.8630	0.5782	89.3	-1.49	0.1391
12-25	-1.0843	0.4817	62.2	-2.25	0.0279
13-25	-0.2214	0.5270	82.5	-0.42	0.6755

Table 5. Differences (±SE) and significance levels of Least Squares Means for paired plot comparisons at 950 DD.

Paired	Estimate	St error	DF	T Value	Pr > | t |
1-2	1.0913	0.5553	71.7	1.97	0.0533
1-12	0.7111	0.5960	61.2	1.19	0.2374
1-13	1.2784	0.6106	60.6	2.09	0.0405
1-25	2.3936	0.7635	90.3	3.13	0.002
2-12	-0.3802	0.6027	59.3	-0.63	0.5305
2-13	0.1871	0.6171	58.7	0.30	0.7629
2-25	1.3023	0.7688	89.1	1.69	0.0937
12-13	.05673	0.6539	52.6	0.87	0.3896
12-25	1.6825	0.7986	82.5	2.11	0.0382
13-25	1.1153	0.8096	81.6	1.38	0.1721

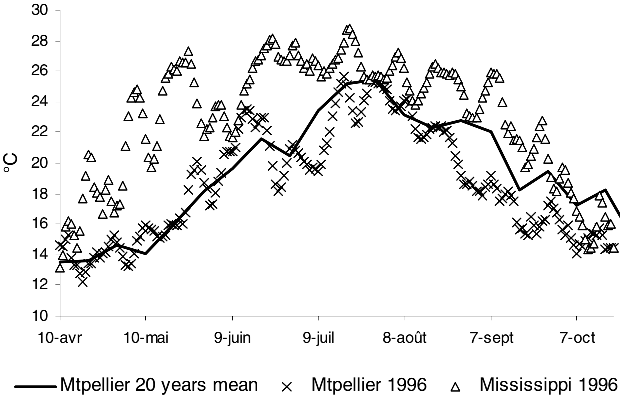

Figure 1. Mean day air temperatures during the season.

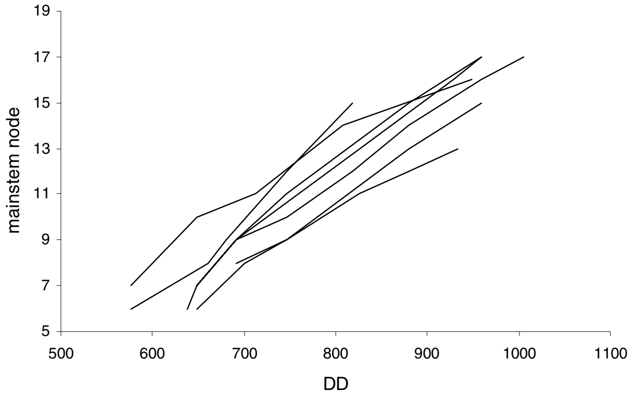

Figure 2. Example of vertical blooming curve variability within a plot.

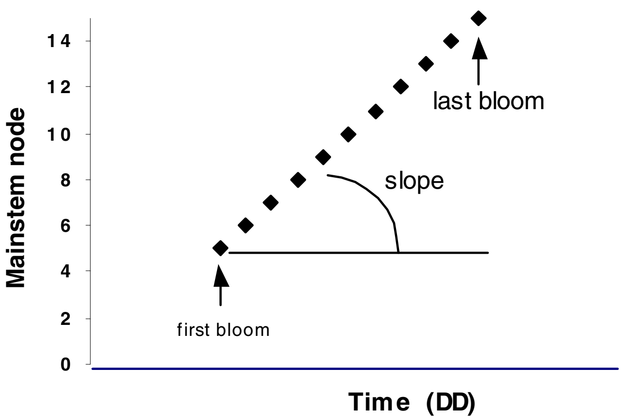

Figure 3. Schematic representation of earliness components.

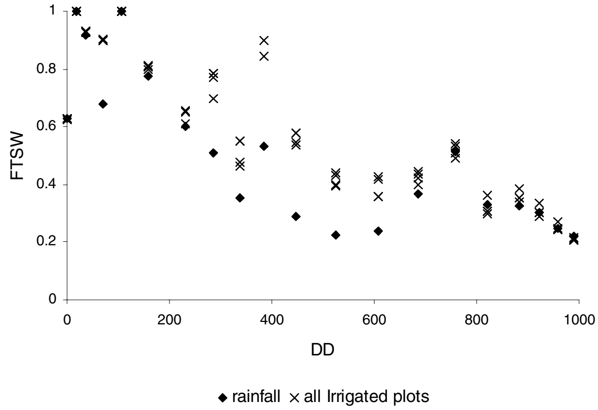

Figure 4. Evolution of Soil water availability during the season.

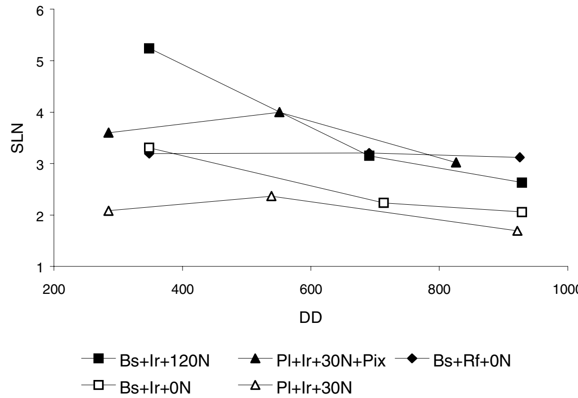

Figure 5. Evolution of Specific leaf N content during the season.

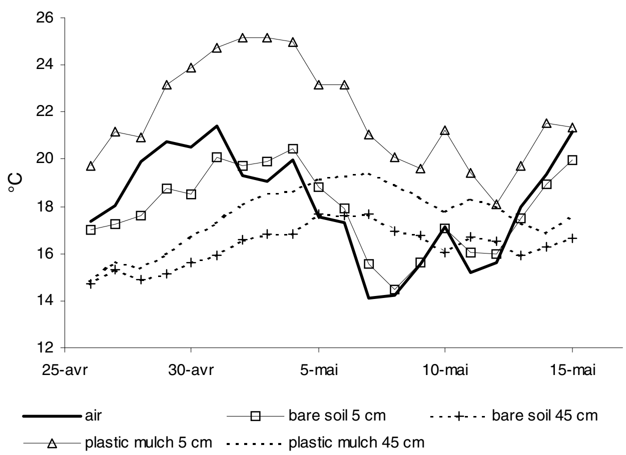

Figure 6. Mean soil and air temperature during emergence.