Effect of Cultivation System on Cotton Development, Seed Cotton Production and Lint Quality

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ABSTRACT

The effect of plant density and row spacing, on growth parameters of cotton (Gossypium hirsutum), seed-cotton production and lint quality was studied by means of a conventional row (CR), a narrow row-low population (NR-LPP) and a narrow row-high population (NR-HPP) cultivation system. Dry mass accumulation rate, relative growth rate, net assimilation rate, fruit index, leaf area ratio, dry mass partitioning, leaf area elongation and specific leaf area were followed. Total dry mass and LAI were higher in NR-HPP system. Considerable differences were revealed between the treatments with the same plant population per unit land area, NR-LPP and CR; with the plants in NR to produce more total dry mass and higher LAI. Stem dry mass was less affected by row spacing and more by plant density along row. Plants in NR-HPP partitioned elevated proportion of total dry mass to vegetative parts. Fruit index and leaf area ratio were lower in NR-HPP and higher in CR. A significant negative correlation existed between LAI and CR. Fruit load considerably affected most growth parameters and significant negative correlation existed between fruit growth rate and growth rate of dry vegetative parts and leaf elongation rate. Fruit load affected less the growth parameters of NR-LPP. Advantage of high population density of NR to produce higher LAI and dry mass in early growth stage did not exploit under the prevailed weather conditions due to excessive canopy and vegetative growth. Seed-cotton production and lint quality were significantly lower in NR-HPP. It is concluded that the NR-HPP system may be not adaptable or a risk under inconsistent weather conditions in a marginal cotton-belt, such that of Greece.

Keywords: Crop growth rate, dry mass, LAI, lint quality, narrow row
Abbreviations: CGR, crop growth rate; CR, conventional row; DAP, days after planting; HPP, high plants population density; LAI, leaf area index; LER, leaf area elongation rate; LGR, leaf growth rate; LPP, low plants population density; LSD, least significant difference; NAR, net assimilation rate; NR, narrow row cultivation system; RGR, relative growth rate; SGR, stem growth rate; UNR, ultra narrow row cultivation system; V/R, vegetative to reproductive (fruiting) ratio

INTRODUCTION

Cotton in Greece is cultivated in a marginal cotton belt, thus a risk arises for excessive vegetative growth when either the weather becomes unfavourable, rainfalls occur early in season or the duration of sunlight is not available for normal reproductive growth. During recent years growers face dramatically rising production costs and declining crop prices. An alternative method to overcome these problems and to optimize profit is to grow cotton by means of a narrow row cultivation system (Nichols et al. 2003). Narrow row (NR) as strategy was introduced with the intent to gain early maturity and cheaper harvesting operations (Brown et al. 1998; Gwathmey 1998) and is considered as potential strategy for the reduction of the production costs (Gerik et al. 1998; Jost and Cothren 2000) by increase seed-cotton yield per land area (Nicholos et al. 2003), shorting in parallel the growing season (Cawley et al. 1998; Gerik et al. 1998). NR or UNR (Ultra narrow row) has been defined with various row spacing and plants population from <25 cm (Atwell 1996) to 38 cm (Parvin et al. 2000). Common characteristic of UNR cotton is the use of high plants population (HPP) compared to conventional row (CR), which often exceeds 25 plants m⁻² (Perkins 1998, Jones 2001).

Yield advantage of NR is due to rapid canopy closure (Jost and Cothren 2000) which permits light interception early in the season (Heitholt et al. 1992) when leaf area index has not reached its optimum. In the progress of the season, the excessive canopy production can lead to shading of the lower canopy, thus reducing the levels of photosynthetically active radiation reaching the lower part of the canopy in high density population of cotton and severely limiting photosynthesis (Guinn 1974). Increase of leaf area index (LAI) that associated with high population densities has been shown to reduce the efficiency of photosynthetic photon flux density interception per plant area (Heitholt 1994). In this case a greater proportion of photoassimilates was directed to vegetative growth rather than reproductive. Thus, plant density would affect yield both, positively with LAI accumulated early in the season, and negatively through lowering the vegetative to fruiting (V/R) ratio (Fowler and Ray 1977). An artificially open canopy improves canopy light environment and after row closure increases seed-cotton yield due to greater production of bolls per m⁻² (Reta-Sanchez and Fowler 2002).

Cultivar performance in the UNR system appears to fluctuate with environmental condition of growing season, with an advantage for UNR system in case of drier season (Nichols et al. 2004). Cotton seeded in NR may be more sensitive to short-term fluctuation in the environmental conditions than cotton grown in CR (Bauer et al. 1998). Biomass partitioning is affected by both wet and dry season. In dry season, plants in both CR and NR (75 cm) partitioned more biomass to vegetative parts comparing to UNR and the opposite holds true in wet season (Jost and Cothren 2000). Increase in cotton yield have been primarily through changes in portioning of dry mass from vegetative to reproductive organs and improve the efficiency of the canopy for light interception and conversion of energy to photosynthates (Cothren 1994). Consistently, the increase of yield in
last century with use of new cotton cultivars was due to ear-
lier transition of these cultivars from the vegetative to
reproductive growth (Wells and Meredith 1984) and due
to decrease of their V/R ratio (Meredith and Wells 1989).
Higher V/R ratio is related in part to high plant population
(Mauney 1986). Because of its perennial (Cothren 1994) and
indeterminate (Hearn 1994) growth habit, control of
vegetative growth in cotton can be difficult under different
environmental conditions. A specific adaptation of cotton to
water regime has a profound impact on crop performance
and is important for managing the crop, particularly main-
taining the balance between vegetative and reproductive
growth (Hearn 1994). That specific habit of cotton may be
the reason for the observed differences in vegetative and
reproductive ratio from year to year or from one region to
another, which are reported in the literature in relation to
population and row spacing (Hearn 1994; Jost and Cothren

High population plants (HPP) density in the NR or CR
system, under the prevailed conditions of Greece, may act
as an additional negative factor in production system. To
our knowledge, little information is available in the litera-
ture with regard to the effect of row spacing and plant den-
sity on growth characteristics at different growth stages,
particularly in the allocation of dry matter in all parts of
plants. Thus, this study focuses on the effect of plant den-
sity and row spacing on plant growth parameters, on seed-
cotton production and lint quality. For each treatment, dry
mass accumulation rate, relative growth rate, net assimila-
tion rate, water content of each organ, fruit index, fruit/leaf
area ratio, percentage of dry mass partitioning, leaf area
elongation, specific leaf area mass are discussed.

MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Research
Station of Palama-Karditsa “National Agricultural Research
Foundation” (N 39° 33'-39°03', E 21° 22'-22°15'), during the 2003
growing season on a silt loam soil. NR or UNR and CR spacing
was 50 cm and 100 cm, respectively. Sowing took place at May 9,
initiation and end of germination (emergence) took place at May
14, and May 21, 2003 respectively. Plants in NR were thinned out
at the stage of the 3rd true leaf, to 17 plants m⁻² in NR-LPP and to
34 plants m⁻² in NR-HPP. Plant density in CR treatment was 17
plants m⁻², typical in a Greek production region. Agricultural prac-
tices were those of local practices; 70 kg ha⁻¹ N prior planting
were applied after soil testing (Table 1). Water was applied via
drip irrigation in July, while during the rest of the growing season
rainfall met plant requirements (during the reproductive rest grow-
ing stage). Weed control practices included pre-plant incorpora-
tion of trifluralin® (trifluralin) and hand rouged treatments to maintain weed-
free plots. The early maturing commercial cultivar of ‘Acala’
growth type (high vigor and long fruiting habit), was evaluated in
the applied production systems.

The experimental design was a randomized complete block
with three treatments and four replications. Each plot, 25 m long,
consisted of four rows in CR spacing and eight rows in NR.
Growth parameters were determined at 32, 46, 60, 80 and 102
days after emergence (43, 57, 71, 92 and 113 days after planting
DAP, respectively). Harvested plants were separated into leaves,
stem, petioles and reproductive organs. Dry weight was deter-
mined at 75°C. Leaf area was determined by Leaf Area Measure-
ment System with conveyor belt accessory (Delta-T Devices LTD,
Burwell, Cambridge, UK). Two lots of harvesting by hand took
place to measure seed-cotton production. 50 randomly bolls for
each replication were used to determine the individual boll weight,
seed and fiber proportion and fiber quality (micronaire and fiber
length). Fiber length (2.5% and 50% span length) were determined
by USTER Fibregraph by, Z Zellweger®, Uster Inc., Knoxville,
TN, (S.N. 98-01-078). Also micronaire was determined by Spinlap,
Micronaire 275 Z Zellweger Uster (S.N. 961152). Graph fit and
statistical analyses were performed by means of Statistica software
package.

RESULTS AND DISCUSSION

Dry mass production and V/R ratio

Above ground harvested dry mass (Fig. 1) was higher in
NR-HPP compared to CR and NR-LPP. Comparison between
treatments with the same plant population and differ-
ent row spacing, i.e. NR-LPP and CR, showed that ac-
cumulation of total dry mass was higher in plants in NR-
LPP and differences between two treatments became more
significant during reproductive growth (after 1st flower
stage). The same pattern was observed for the LAI. These
results may be related with the better distribution of plant
population in the case of NR system, which may be more
effective to intercept the light. Closer spacing and elevated
population in UNR lead to more rapid canopy closure than in
CR (Heitholt et al. 1992; Jost and Cothren 2000) and this
lead to an increase in light interception (Krieg 1996). A
significant positive correlation was found to exist between LAI
and total dry mass and the correlation coefficients were sig-
nificant at p<0.001 for all treatments (r = 0.75, 0.83 and
0.80 for CR, NR-LPP and NR-HPP, respectively). Thus, the
higher total dry mass in NR spacing was due to higher LAI.
These results showed that, plant density and row spacing
equally affected the total dry mass and the leaf area index.

Vegetative dry mass was significantly higher in NR-
HPP than in NR-LPP and CR, however (except the last
sample) dry mass of reproductive structure was the same or
with no statistically significant differences among three
 treatments and in final sample fruit dry mass tended to be
more in NR-LPP.

These results suggest that plants in NR, particularly
when plant population density was high, produced more
total dry mass, but high proportion of produced dry mass
was directed to vegetative parts. This fact was sustained by
the results of fruit index (Table 2), which was significantly
lower in NR-HPP, higher in CR and intermediate in NR-
LPP. The lower V/R ratio or fruit index (expressed as g
reproductive mass 100⁻¹ g vegetative mass) and fruiting-leaf
area ratio, indicate that plants of NR-HPP produced exces-
sive vegetative growth and high canopy, which negatively
affected the reproductive growth, because of less penet-
ratron of sunlight into canopy (Guinn 1974) and less air
movement, thus less CO₂ exchanges and high humidity at
the bottom of canopy (Cothren 1994). Also, canopy in UNR
showed higher relative humidity and lower temperature
(Marois et al. 2004). These conditions lead to abscission of
fruits. It is known that improvement of light penetration by
mechanical topping or leaves pruning, increased of bolls
number (Rita-Samchen and Fowler 2002). Plant density
would affect both yield positively with LAI accumulated
early in the season and negatively through lowering the V/R
ratio, because larger proportion of photosynthesates was
directed to vegetative growth (Fowler and Ray 1977).
Comparison between NR-HPP vs NR-LPP showed higher
significant difference in the dry weight of leaves (was signi-
ficant at P<0.001, by least significant deference test (LSD)
at 93 and 114 DAP) and less in the dry weight of stem (P≤

Table 1 Soil analysis.

<table>
<thead>
<tr>
<th>Depth soil sample/layer</th>
<th>CaCO₃%</th>
<th>PH</th>
<th>P ppm</th>
<th>Mg K₂O 100 g⁻¹ soil</th>
<th>Mechanical analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>1.26</td>
<td>8.2</td>
<td>17.5</td>
<td>5.1</td>
<td>Sand 39 Silt 16 Clay 16</td>
</tr>
<tr>
<td>30-60</td>
<td>3.36</td>
<td>8.4</td>
<td>5.5</td>
<td>0.7</td>
<td>Silt 15 Clay 14 SiCl 14</td>
</tr>
<tr>
<td>60-90</td>
<td>4.62</td>
<td>8.3</td>
<td>4.0</td>
<td>0.4</td>
<td>Clay 19 Silt 50 SiCl 30</td>
</tr>
</tbody>
</table>

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Dry mass accumulation rate

SGR (g m\(^{-2}\) day\(^{-1}\)) in NR system was higher in HPP plant density when fruit load capacity was low (43-71 DAP, square set to boll set). In contrast, when fruit load became significant, it became higher in NR-LPP. Increase of fruit load produced high reduction of SGR (Table 3), particularly in case of CR, and it became 3-5 times less during reproductive growth compared to vegetative growth. Thus, a peak of SGR occurred at different time among treatments and earliest occurred in NR-HPP and CR (43-57 DAP-square set to 1^st flower), while in NR-LPP, this peak occurred at later growth stage (57-71 DAP) and SGR maintained in relative high values during reproductive growth. These data suggest that (for the cultivar type under evaluation characterized by long fruiting and high vigor habit), SGR was affected more by the plant density along the row and less by the row spacing between the rows. This data was not confirmed for compact type, and short fruiting and lower vigor habit cultivar (unpublished data).

Opposite of stem LGR (g m\(^{-2}\) day\(^{-1}\)) during the repro-
Partitioning of the daily produced dry mass to reproductive organs in all treatments and before fruit load become significant (43-57 DAP, square set-1st flower). CGR (Table 3) was significantly higher in NR-HPP compared to CR and NR-LPP. The peak of CGR in high plant density along the row (NR-HPP and CR) occurred at the stage of 1st flower set (43-57 DAP), while in NR-LPP (lower plants density along the row) CGR maintained high values until the bolls-set stage. At the end of the season 92-114 DAP, fruit accumulation rate was higher in NR-LPP, intermediate in NR-HPP and lower in CR. Also, peak of leaves dry mass accumulation rate occurred simultaneously in all treatments and before fruit load become significant (43-57 DAP, square set-1st flower).

CGR (Table 3) was significantly higher in NR-HPP compared to CR and NR-LPP. The peak of CGR in high plant density along the row (NR-HPP and CR) occurred at the stage of 1st flower set (43-57 DAP), while in NR-LPP (lower plants density along the row) CGR maintained high values until the bolls-set stage. At the end of the season 92-113 DAP, fruit accumulation rate was higher in NR-LPP, but was higher in CR between 71 and 93 DAP.

### Dry mass partitioning

Partitioning of the daily produced dry mass to stem and leaves was dramatically altered during fruit development (Table 4). During vegetative growth, 66%, 67% and 67% of daily produced dry mass partitioned to leaves in CR, NR-LPP and NR-HPP respectively. However, when fruit load became high, this partitioning of daily produced dry mass became 19%, 21% and 36% for leaves, 22%, 48% and 36% for stem and 59%, 31% and 28% for fruit, in CR, NR-LPP and NR-HPP respectively. These results showed that every fruit percentage gain in daily produced dry mass coincided with a loss on percentage of leaves against the stem. This was particularly clear in case of NR-LPP with the lower plant density along the row. Plants in CR partitioned more proportion of daily produced biomass into fruit and this was clearer at 72-93 DAP compared to the other treatments. From these results also comes out, that competition between fruits load and vegetative parts was at the expense of leaf growth than of stem growth, when plant population along the row was lower.

Plants in NR-HPP directed the lower percentage of daily produced total dry mass to fruit. Partitioning of dry mass was affected by seasonal changes. In wet season, plants in CR partitioned more dry mass to reproductive structure than in UNR, and the opposite occurred in dry season (Jost and Cothren 2000). It is affected also by soil type, potassium and nitrogen fertilization (Clawson Jost and Cothren 2000). It is affected also by soil type, potassium and nitrogen fertilization (Clawson 2001) and by genotypes (Bange and Clement and Gathmey 2007) and by genotypes (Bange and Milroy 2004). When plant density is high in UNR system, less biomass tended to portioned into reproductive organs in silt clay loam soil and more when plants grown in heavy clay soil (Jost and Cothren 2001), obviously due to the differences in water availability between soil types. Increased plant density in irrigated cotton, decreased boll number and individual boll weight, while in rain-fed cotton was not affected by varying plant density (Boquent 2005). These findings support the assumption of specific cotton habit and its sensitivity to water regime (Hearn 1994) thus, maintaining of control of vegetative growth in cotton can be difficult under environmental condition (Cothren 1994). Significant negative correlation existed between fruit dry mass accumulation rate and dry mass accumulation rate of vegetative parts with leaf area elongation rate (Table 5).

### Table 2 Fruit index (as g fruit 100g-1 vegetative parts, dw base) and fruit-leaf area ratio in CR, NR-LPP and in NR-HPP systems during plant development from emergence to opening bolls (means ± standard error - SE).

<table>
<thead>
<tr>
<th>Days after planting</th>
<th>Treatments</th>
<th>59 (45-59)</th>
<th>73 (59-73)</th>
<th>93 (73-93)</th>
<th>114 (93-114)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit index (g 100 g-1)</td>
<td>CR</td>
<td>5.5 ± 0.41</td>
<td>14.4 ± 1.11</td>
<td>33.4 ± 3.05 a</td>
<td>74.2 ± 0.66 a</td>
</tr>
<tr>
<td></td>
<td>NR-LPP</td>
<td>5.9 ± 0.33</td>
<td>13.1 ± 0.66</td>
<td>21.8 ± 1.79 b **</td>
<td>63.0 ± 2.63 b **</td>
</tr>
<tr>
<td></td>
<td>NR-HPP</td>
<td>4.8 ± 0.07</td>
<td>11.5 ± 2.34</td>
<td>19.0 ± 0.32 b **</td>
<td>44.9 ± 1.72 c ***</td>
</tr>
<tr>
<td>LSD (P: 0.05, 0.01, 0.001)</td>
<td>NS</td>
<td>NS</td>
<td>5.60, 8.49, 13.64</td>
<td>10.75, 16.26, 26.18</td>
<td></td>
</tr>
</tbody>
</table>

| Fruit-leaf area ratio (g m-2) | CR | 6.3 ± 0.82 | 18.0 ± 0.49 | 37.6 ± 3.6 a | 122.8 ± 3.63 a |
| NR-LPP | 7.4 ± 0.52 | 17.1 ± 1.85 | 27.6 ± 2.33 b ** | 106.5 ± 4.82 b ** |
| NR-HPP | 5.7 ± 0.15 | 14.9 ± 0.37 | 24.7 ± 0.54 b ** | 87.2 ± 2.55 c ** |
| LSD (P: 0.05, 0.01, 0.001) | NS | NS | 6.69, 10.13, 16.28 | 15.44, 23.39, 37.60 |

### Table 3 Growth rate of stem (SGR), leaves, fruit and crop growth rate (CGR) in CR, NR-LPP and in NR-HPP during plants development from emergence to opening bolls (means= SE).

<table>
<thead>
<tr>
<th>Days after planting</th>
<th>Treatments</th>
<th>0-45</th>
<th>45-59</th>
<th>59-73</th>
<th>73-93</th>
<th>93-114</th>
</tr>
</thead>
<tbody>
<tr>
<td>g dw m-2 day-1 stem growth rate</td>
<td>CR</td>
<td>1.12 ± 0.05 b</td>
<td>8.0 ± 0.74 b</td>
<td>6.5 ± 0.38 c</td>
<td>2.0 ± 0.12 b</td>
<td>2.6 ± 0.23 b</td>
</tr>
<tr>
<td></td>
<td>NR-LPP</td>
<td>1.13 ± 0.08 b</td>
<td>8.1 ± 0.61 b</td>
<td>8.9 ± 0.22 b **</td>
<td>7.4 ± 0.52 a **</td>
<td>3.9 ± 0.65 a **</td>
</tr>
<tr>
<td></td>
<td>NR-HPP</td>
<td>1.47 ± 0.14 a **</td>
<td>11.4 ± 0.23 a **</td>
<td>10.6 ± 0.64 a **</td>
<td>6.3 ± 0.39 a ***</td>
<td>4.0 ± 0.35 a **</td>
</tr>
<tr>
<td>LSD (P: 0.05, 0.01, 0.001)</td>
<td>0.17, 0.26, 0.42</td>
<td>1.06, 1.60, 2.59</td>
<td>1.38, 2.1, 3.36</td>
<td>1.27, 1.92, 3.1</td>
<td>1.14, 1.76, 2.79</td>
<td></td>
</tr>
</tbody>
</table>

| Leaves growth rate | CR | 2.19 ± 0.05 | 8.5 ± 0.76 b | 4.6 ± 0.20 | 1.8 ± 0.28 b *** | Leaf abscission |
| NR-LPP | 2.40 ± 0.13 | 9.7 ± 0.53 b | 6.1 ± 0.51 | 3.3 ± 0.57 b * | - |
| NR-HPP | 3.00 ± 0.33 | 12.6 ± 0.45 a ** | 7.8 ± 0.92 | 6.4 ± 0.38 a | - |
| LSD (P: 0.05, 0.01, 0.001) | NS | 1.81, 2.74, 4.41 | 1.92, 2.91, 4.68 | 1.56, 2.37, 3.81 | |

| Fruit growth rate | CR | - | 1.3 ± 0.09 b | 3.7 ± 0.31 | 5.8 ± 0.97 | 10.4 ± 0.52 b |
| NR-LPP | - | 1.5 ± 0.87 a | 4.0 ± 0.54 | 4.7 ± 0.27 | 13.6 ± 1.12 a* |
| NR-HPP | - | 1.6 ± 0.64 a ** | 4.4 ± 0.19 | 4.9 ± 0.21 | 10.7 ± 0.40 b |
| LSD (P: 0.05, 0.01, 0.001) | - | 0.12, 0.19, 0.30 | NS | NS | 2.64, 4.0, 6.43 |

| TOTAL (or crop growth rate) | CR | 3.32 ± 0.02 b | 17.8 ± 1.49 b | 14.8 ± 0.43 c | 9.6 ± 1.11 b | 9.7 ± 0.57 |
| NR-LPP | 3.51 ± 0.20 b | 19.3 ± 1.16 b | 19.0 ± 1.11 b ** | 15.4 ± 0.97 a ** | 10.0 ± 2.20 |
| NR-HPP | 4.47 ± 0.47a | 25.6 ± 0.64 a ** | 22.8 ± 1.72 a ** | 17.5 ± 0.54 a | 7.5 ± 0.56 |
| LSD (P: 0.05, 0.01, 0.001) | 0.70, 1.06, 1.71 | 2.33, 3.54, 5.69 | 2.99, 4.52, 7.27 | 3.23, 4.89, 7.86 | NS |

Means within a column (comparison between cultivation systems) followed by same letter are not significantly different by the least significant difference test (LSD) at 0.05*, 0.01** and 0.001*** probability (P) level. NS; not significant at P = 0.05.
These results indicate that fruit load is a strong sink for assimilates and affected strongly the growth rate of the vegetative parts. Generally, plant density and row spacing affected partitioning of dry mass, but these effects were more dependent on the physiological plant stage and on fruit load capacity and altered with physiological stages. We conclude that partitioning of dry mass is affected by factors influencing the balance of vegetative and reproductive growth, such as plant density and row spacing.

### Leaf area parameters

LAI was not affected only by plant density, but also by the row spacing. Thus LAI was higher in NR-HPP than other treatments, and was higher in NR-LPP compared with CR, despite of their same plants density per unit land area. These differences between treatments, especially between CR and NR-LPP, became higher during reproductive growth. Due to higher LAI in NR-HPP, closer rows accomplished more expeditiously in case of NR spacing. Peak of LAI occurred simultaneously in all treatments at 91 days after planting (DAP), however peak in leaf area elongation rate (LER) occurred at 43–57 DAP (square set to 1st flower set). This peak in LAI and LER was particularly higher in NR-HPP and lower in NR-LPP and CR. Significant negative correlation (r = -0.76, -0.65, -0.93) existed between LAI and fruit growth rate at p<0.01, p<0.05 and p<0.001 in CR, NR-LPP and NR-HPP respectively. Fruit load less affected LER of NR-LPP and more of CR and NR-HPP. As fruit increased, LER of CR became significantly lower than in NR treatments. At vegetative growth, in the absence of fruit, LER did not present significant differences among treatments. These results showed that row spacing and plant density did not affect in the same way the leaf area parameters and dry mass during vegetative and reproductive growth, but these effects are altered analogous of fruit sink capacity. Also, these data showed that the fruit load, as a strong sink, may alter many physiological processes and sometimes overlap the effect of other factors during plant growth. Interaction existed between the effects of row spacing and plant density and the effect of fruit load on growth parameters during reproductive growth. Plants that produced high LAI, showed a lower fruit-leaf area ratio and fruit index, thus plants in CR showed the higher fruit-leaf area ratio and fruit index, whereas plants in NR showed the higher fruit-leaf area ratio and fruit index.

Row spacing and plant density did not clearly affect specific leaf mass (SLM, Table 6). At stage of 1st flower, while was higher in NR-LPP, at last two samplings (peak bolls growth) SLM was lower in this treatment than in others. SLM did not significantly correlated with fruit load.
growth rate, but a significant negative correlation (p<0.01) existed between SLM and LAI in CR and NR-LPP at p<0.01 (r = -0.74 and -0.77 respectively), while in NR-HPP it was less significant (p=0.05, r = -0.52).

**Net assimilation rate and relative growth rate**

RGR and NAR (Table 7) followed the same alternation pattern during plant growth. These growth parameters were higher at vegetative growth (from emergence to square set) and then they progressively decreased with the fruit load increase. Peak photosynthesis canopy was in flowering and decreased with season, especially decreasing during the important fruiting growth period (Reddy and Hodges 1998). Decline of photosynthesis was due to decline in leaf photosynthesis of young leaves as plant aged and aging of older leaves rather than due to reduction in leaf area (Kasemsap and Crozat 1998). Row spacing and plant density differently affected the NAR and RGR during plant growth. From square set to the 1st flower stage, NAR and RGR were lower in NR-LPP, and in the same degree higher in CR and NR-HPP. This result was opposite to other findings (Bednarz et al. 2000), however in agreement in later stage (1st flower to bolls set). At this stage NAR and RGR were higher in NR-LPP than in NR-HPP and CR. The higher RGR and NAR in NR-LPP are explained by the differences among treatments in CGR, which from square set to bolls set stage (43-71 DAP) were maintained in higher values, and presented a plateau of high values in NR-LPP, however in CR and NR-HPP were decreased progressively after a peak which occurred at stage of square set to 1st flower set (43-57 DAP). Thus, plants in NR-LPP showed less decreased of net NAR and RGR in the stage of bolls set, in comparison with other treatments.

**Seed-cotton production and lint quality**

Seed-cotton production (Table 8) was significantly less (p<0.01) in NR-LPP compared to CR, NR-LPP and CR-HPP** (‘aside from three treatments, seed-cotton production was measured in other CR treatment with 25 plants m	extsuperscript{-2}). Differences between CR and NR-LPP in seed-cotton production were insignificant (p=0.05). Plants in NR-HPP produced significantly (p<0.01) less individual boll weight and lower fibre proportion (or higher seed proportion) compared to others treatments (Table 7). Lower seed-cotton production in NR system and high plant density (HPP) may be related to water regime under the effect of slit clay loam soil type (as is our case), because in this soil type, less biomass tended to portioned into reproductive organs (Jost and Corthren 2001) and under the effect of wet season (Jost and Corthren 2000) as this came out from our result as previous was reported in V/R ratio. Also, high portion of bolls in case of NR-LPP did not open or mature (data not shown). Thus, we can conclude that, conditions that lead to excessive vegetative growth and high vigor as soil type and wet season affect more negative seed-cotton production in NR, particularly when plant population is high.

These conditions lead to abscission of fruits and affect negatively the maturing or opening of bolls. Thus, high population plants density of NR system may be not adapt or a risk under inconsistent weather condition particularly in marginal cotton-belt. Micronaire, a measure of fibre fineness and maturity, tended to be significantly (p<0.05) lower in the NR system compared to CR, especially under the NR-HPP system. This result was in agreement with some reports (Gerik et al. 1998; Vories et al. 1999), but not with other ones (Jost and Cothren 2001). Lower micronaire in NR-HPP may be related with excessive vegetative growth or shading of lower leaves (Hake et al. 1996). Plants in NR-HPP produced less significant (p<0.05) 50% fibers Span Length and lower Uniformity Ratio (expressed as 50% span length^2 2.5% span length) compared to other treatments (CR and CR-HPP and NR-LPP), but these differences between treatments on 2.5% Span Length were insignificant (p<0.05).

**CONCLUSIONS**

Plants in NR-HPP treated produced higher LAI and more total dry mass compared to NR-LPP ones, while plants in NR-LPP produced higher LAI and more dry mass compared to CR. These differences between treatments in total dry mass accumulation were due to differences in vegetative growth. Reproductive dry mass was the same or with no significant differences between treatments. Thus fruit-leaf area ratio and fruit index were higher in CR than in NR spacing and were less in NR of HPP plants density. Higher
plant density of NR spacing produced excessive vegetative growth and canopy which affected negatively dry mass of reproductive organs and decreased the boll retention or caused abscission of fruiting organs. Siebert and Stewart (2006) found that, in some cases, lint yield was inversely related to plant population, thus a significant yield response occurred with meipiquat chloride application strategy (restricts vegetative growth). This decreased of lint yield by increase of plant density was found in case of irrigated cotton and not of rain-fed cotton (Boquet 2005).

Plants of NR-LPP particularly after boll set accumulated a higher fraction of the produced daily total mass to the stem in comparison with CR and NR-HPP. In these plants, peak of SGR and CGR of NR-LPP occurred at later stage (after fruit set) in comparison with CR and NR-HPP (before boll set). Fruit load affected less CGR and SGR in case of lower plant density along the row (NR-LPP) and more in case of higher plants density along the row (CR and NR-HPP).

Stem and fruit data showed that competition between fruit and stem growth was lower when plant density along the row is reduced. Fruit load affected significantly all growth parameters and some time overlap the effects of plant density and row spacing. Higher competition existed between fruit and leaves and less between fruit and stem, especially in lower plants density along the row. The most parameters of growth in plants of lower plant density population along the row (NR-LPP) were less affected by fruit load in comparison with other treatments (NR-HPP and CR). Interaction between fruit load affected row spacing and plant density on growth parameters, especially in CGR and in partitioning of dry mass. High plant density in narrow spacing raised a risk in marginal cotton-belt region, because of hazard of inconsistent weather parameters (as rainfalls during the reproductive growth or boll filling), that stimulate excessive vegetative growth and lead to fruit shed and boll rot, especially in case of high plants density in NR system.

Advantage of NR to produce higher LAI in early growth stage and thus higher dry mass in comparison with CR did not exploit, especially when plant density is high, under the experimental conditions and in particular in mar- ginal Cotton-Belt region, because high percentage of dry matter was directed to vegetative growth. In case of NR treatments with lower plants density showed best partitioning of dry mass to reproductive growth than in high plant density and may be more effective under these conditions. Thus, seed-cotton production was significantly lower in NR-HPP than in other treatments. Lint quality was lower in NR system compared to CR, especially when plant population density was higher (NR-HPP). Micronaire, 50% Span and fibres Uniformity Ratio were significantly lower in NR-HPP than other treatments, while differences between treatments on 2.5% span length were insignificant. Plants in NR-HPP produced less individual boll weight and lint proportion (or higher seed proportion). Bednraz et al. (2006a) found that as plant density increased, lint mass boll-1 increased, individual boll number and lint mass m-2 of land area increased, which resulted in increase lint yield m-2 of land area. They (Bednraz et al. 2006b) also found that reducing plants density increased the source to sink ratio during boll filling, resulting in improved fibre properties.

Generally, our results (growth parameters, seed-cotton production and lint quality under different cultivation sys-
tem) were in line with previous reports and with others, also disagreement aspects about the effectiveness of production systems was observed between different reports, which were reported in this paper. Different environmental conditions geographic position, or other parameters, which are related with the water regime, under which these experi-
ments were conducted, may be the reason of deferent results. Water regime is, especially, significant factor for cotton growth, because of its perennial and indeterminate growth habit, which was reported analytically by Heath (1994). NR or UNR, as production system, are suggested and widely used in USA, and Australia, whereas in Europe (Cotton is cultivated only in Greece and very less in Spain) are seldom used. Production system of NR or UNR, especially, under high plant density, can be more suitable for drier region or for drier season, or environmental conditions that do not promote excessive vegetative growth. Effect of production system (row spacing and plant density) on growth parameters is not the same under deferent cotton water regime. For example, in case of irrigated cotton, rainfalls during reproductive growth or filling boll or in the end of season (which frequently occurs in marginal cotton belt as in Greece), caused higher damage (more boll rot, higher number of immature bolls, more excessive vegetative growth or re-growth, thus higher decrease in yield and lint quality) on production system of NR or UNR compared to CR system, especially under high plant density (unpublished data).

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REFERENCES
Bednraz CW, Bridges DC, Brown SM (2000) Analysis of cotton yield stabi-
ility across population densities. Agronomy Journal 92, 128-135
us TN, pp 88-91
Fowler JL, Ray LI (1977) Response of two cotton genotypes to five equidis-
tant spacing patterns. Agronomy Journal 69, 733-738
cil USA, pp 1406-1407
wide Cotton Conference, Nashville TN, 9-12 Jan., National Cotton Council of America, Memphis, TN, pp 91-97
tralia, 14-17 Feb., 1994, pp 66-90
Heathfield JJ (1994) Canopy characteristics associated with deficient and exces-
sive cotton plant populations densities. Crop Science 34, 1291-1297
Heathfield JJ, Pettigrew WT, Meredith WR Jr. (1992) Light interception and
lint yield of narrow-row cotton. *Crop Science* 32, 728-733


