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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, fruit/leaf area ratio, dry mass partitioning, leaf area elongation and specific leaf area mass 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 fruit-leaf area ratio were lower in NR-HPP and higher in CR. A significant negative correlation existed between SLM and LAI. Fruit load considerably affected most growth parameters and significant negative correlation existed between fruit growth rate and growth rate of 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 incentive 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 compared 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

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last century with use of new cotton cultivars was due to earlier transition of these cultivars from the vegetative to reproductive growth (Wells and Meredih 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 (Cothrern 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 maintaining 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 2000, 2001).

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 literature with regard to the effect of row spacing and plant density 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 density 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 assimilation 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 practices 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 growing stage). Weed control practices included pre-plant incorporated triflan® (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 determined at 75°C. Leaf area was determined by Leaf Area Measurement 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 different row spacing, i.e. NR-LPP and CR, showed that accumulation of total dry mass was higher in plants of 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 significant at $p \leq < 0.001$ 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 excessive vegetative growth and high canopy, which negatively affected the reproductive growth, because of less penetration of sunlight into canopy (Guinn 1974) and less air movement, thus less CO_2 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 (Reta-Sanchez 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 photoassimilates 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 significant at $P \leq 0.001$, by least significant deference test (LSD) at 93 and 114 DAP) and less in the dry weight of stem ($P \leq$

Table 1 Soil analysis.

Depth soil sample(layer)	$CaCO_3$%	PH	P ppm	Mg K_2O 100 g^{-1} soil	Mechanical analysis			
					Sand	Silt	Clay	
0-30	1.26	8.2	17.5	5.1	39	45	16	L
30-60	3.36	8.4	5.5	0.7	35	51	14	SiL
60-90	4.62	8.3	4.0	0.4	19	51	30	SiCL

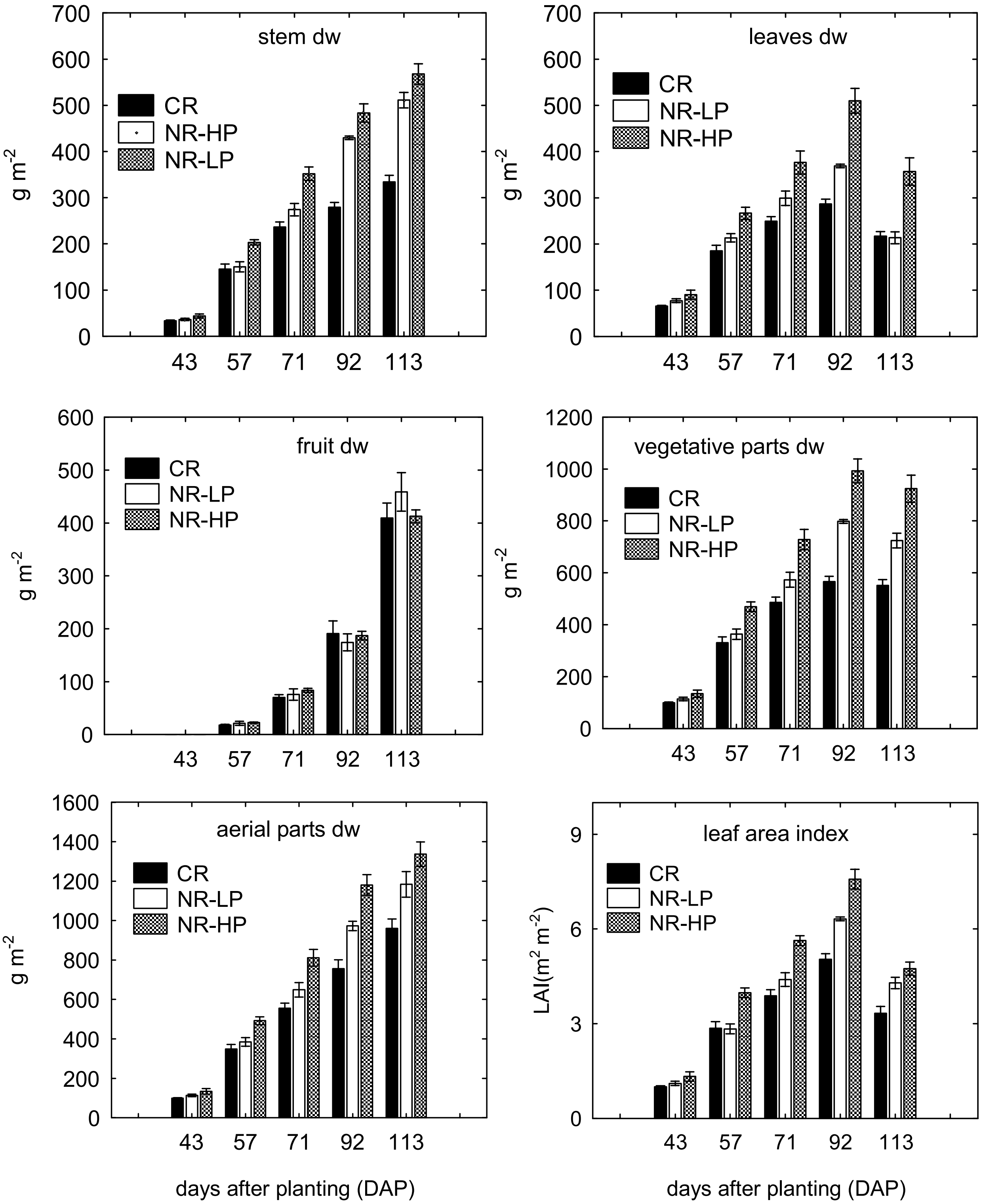

Fig. 1 Means of dry matter of stem, leaves (leaves and petioles), fruits, total vegetative parts, and total aerial parts, and LAI, under effects of row spacing and plants population density at various DAP. Vertical lines represent ± standard error (SE).

0.05, on the same dates). However, comparison between NR-LPP and CR (**Fig. 1**) presented less or non-significant differences in dry weight of leaves ($P \leq 0.05$ at 93 DAP and was not significant at 114 DAP), while these differences in dry weight of stem between the two systems were significant very high ($P \leq 0.001$).

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 1st 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-

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).

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

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

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).

days after planting					
Treatments	**0-45**	**45-59**	**59-73**	**73-93**	**93-114**
g dw m^{-2} day^{-1} stem growth rate					
CR	1.12 ± 0.05 b	8.0 ± 0.74 b	6.5 ± 0.38 c	2.0 ± 0.12 b	2.6 ± 0.23 b
NR-LPP	1.13 ± 0.08 b	8.1 ± 0.61 b	8.9 ± 0.22 b**	7.4 ± 0.52 a***	3.9 ± 0.65 a*
NR-HPP	1.47 ± 0.14 a**	11.4 ± 0.23 a***	10.6 ± 0.64 a****	6.3 ± 0.39 a***	4.0 ± 0.35 a*
LSD $_{(P: 0.05, 0.01, 0.001)}$	0.17, 0.26, 0.42	1.06, 1.60, 2.59	1.38, 2.1, 3.36	1.27, 1.92, 3.1	1.14, 1.76, 2.79
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 ± 0.87a*	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.

ductive growth stages was apparently higher in NR-HPP, intermediate in NR-LPP 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 *et al* 2006; 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 $plant^{-1}$ 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 4 Distribution (%) of crop growth rate (or daily produced dry mass) into plants parts of CR, NR-LPP and in NR-HPP during plants development from emergence to opening bolls (means± SE).

days after planting					
Treatments	**0-45**	**45-59**	**59-73**	**73-93**	**93-114**
% Stem					
CR	33.8 ± 0.58	44.7 ± 1.53	43.9 ± 1.53	22.0 ± 2.55 c	20.1 ± 1.61 b
NR-LPP	32.0 ± 0.53	41.9 ± 0.97	47.4 ± 2.41	47.9 ± 0.63 a***	21.8 ± 1.52 b
NR-HPP	33.2 ± 3.62	44.5 ± 0.80	46.7 ± 0.84	35.7 ± 1.77 b**	27.2 ± 2.26 a*
LSD (P: 0.05, 0.01, 0.001)	NS	NS	NS	6.40, 6.69, 15.57	5.99, 9.1, 14.61
% Leaves					
CR	66.2 ± 1.20	48.0 ± 1.22	31.1 ± 2.14	18.6 ± 2.71 b	Leaf abscission
NR-LPP	67.9 ± 1.10	50.1 ± 1.30	32.4 ± 0.95	21.2 ± 2.35 a**	-
NR-HPP	66.9 ± 3.50	49.2 ± 0.80	34.0 ± 1.55	36.2 ± 1.85 a***	-
LSD (P: 0.05, 0.01, 0.001)	NS	NS	NS	6.41, 9.71, 15.62	
% Fruit					
CR		7.3 ± 0.59 ab	25.0 ± 1.57 a	59.4 ± 4.84 a	79.9 ± 1.70 a
NR-LPP		7.9 ± 0.43 a*	20.3 ± 2.21 ab	30.9 ± 2.95 b***	78.2 ± 2.50 ab
NR-HPP		6.3 ± 0.24 b	19.3 ± 0.80 b*	28.1 ± 0.67 b***	72.8 ± 2.26 b*
LSD (P: 0.05, 0.01, 0.001)		1.34, 2.04, 3.27	5.97, 9.05, 14.55	7.68, 11.64, 18.70	6.10, 9.09, 14.61

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.

Table 5 Correlation matrix based on means of fruit growth rate (accumulation rate) and means of growth rates of stem, leaves, petioles and vegetative parts, and means of leaf elongation rate (LER), during reproductive growth (sample with leaves abscission did not inclusive). Values above represent Pearson's correlation coefficients.

	Treatments	**Leaves**	**Stem**	**Petioles**	**Vegetative Parts**	**LER**
Fruit	CR	-0.83***	-0.77*	-0.82**	-0.83***	-0.76**
	NR-LPP	-0.85***	-0.14	-0.43	-0.73**	-0.65*
	NR-HPP	-0.87***	-0.63*	-0.63*	-0.81**	-0.93***

* $p \leq 0.05$ ** $p \leq 0.01$, *** $p \leq 0.001$

Table 6 Leaf area elongation rate (LER) and specific leaf mass (SLM) of CR, NR-LPP and in NR-HPP during plants development from emergence to bolls opening (means ± SE).

days after planting					
Treatments	**0-45**	**45-59**	**59-73**	**73-93**	**93-114**
LER, $cm^2\ m^{-2}\ day^{-1}$					
CR	333.9 ± 10.5 b	1324 ± 127.5 b	735 ± 82.7 b	549 ± 61.1 b	Leaf abscission
NR-LPP	343.1 ± 20.9 b	1232 ± 66.3 b	1115 ± 55.0 a**	915 ± 74.6 a**	-
NR-HPP	442.9 ± 49.7 a*	1893 ± 58.6 a***	1181 ± 60.5 a**	924 ± 76.1 a**	-
LSD (P: 0.05, 0.01, 0.001)	73, 110, 177	219, 332, 533	212, 321, 517	287, 334, 698	
SLM $g\ m^{-2}$					
CR	57.3 ± 1.10	54.5 ± 1.87 b	53.5 ± 1.11	46.7 ± 1.30 b	56.8 ± 1.54 b
NR-LPP	60.1 ± 1.10	63.5 ± 1.33 a*	56.3 ± 0.66	46.1 ± 1.10 b	40.6 ± 1.00 c*
NR-HPP	59.6 ± 0.72	56.7 ± 1.68 b	55.0 ± 2.34	54.4 ± 1.41 a**	65.3 ± 2.66 a**
LSD (P: 0.05, 0.01, 0.001)	NS	6.15, 9.32, 14.97	NS	4.04, 6.13, 9.86	7.12, 10.79, 17.34

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 are depended on the physiological plant stage and on fruit load capacity and altered with physiological plants stage, becoming more complex in the reproductive growth stage. 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 others 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 DAP, however peak in leaf area elongation rate (LER) occurred at 43-57 DAP (square set to 1st flower set). At this peak, LER (**Table 6**) 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 LER and fruit growth rate at $p \leq 0.01$, $p \leq 0.05$ and $p \leq 0.001$ 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 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 are 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 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 to1st 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-HPP 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^{-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 Cothren 2001) and under the effect of wet season (Jost and Cothren 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 fiber 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^{-1} 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 treatment 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

Table 7 Relative growth Rate (RGR) and net assimilation (NAR) in CR, NR-LPP and NR-HPP during plants development from emergence to opening (means± SE).

days after planting					
Treatments	**0-45**	**45-59**	**59-73**	**73-93**	**93-114**
RGR, mg g^{-1} day^{-1}					
CR	102.2 ± 0.56 b	89.2 ± 3.45	33.6 ± 2.07 b***	14.6 ± 1.77 b	11.4 ± 0.69 a
NR-LPP	103.4 ± 1.27 b	80.0 ± 2.34	49.8 ± 1.07 a	19.4 ± 1.83 a*	9.2 ± 1.60 ab
NR-HPP	108.5 ± 2.38 a*	93.9 ± 5.18	36.6 ± 1.33 b**	17.9 ± 0.44 ab	5.9 ± 0.29 b*
LSD $_{(P: 0.05, 0.01, 0.001)}$	3.26, 4.94, 7.94	NS	5.82, 8.83, 14.19	4.4, 6.66, 10.71	3.52, 5.34, 8.58
NAR, g m^{-2} day^{-1}					
CR	15.1 ± 0.11 b**	10.0 ± 0.37 ab	4.5 ± 0.28 b	2.1 ± 0.18 b	2.4 ± 0.13 a
NR-LPP	14.7 ± 0.13 b***	8.5 ± 0.28 b	6.5 ± 0.08 a**	2.9 ± 0.25 a*	1.9 ± 0.34 ab
NR-HPP	16.0 ± 0.24 a	10.7 ± 0.64 a*	4.8 ± 0.22 b	2.7 ± 0.04 ab	1.3 ± 0.06 b*
LSD $_{(P: 0.05, 0.01, 0.001)}$	0.52, 0.79, 1.27	1.85, 2.80, 4.50	0.86, 1.30, 2.08	0.68, 1.04, 1.67	0.73, 1.11, 1.78

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.

Table 8 Means of seed-cotton production, individual bolls weight, fiber proportion, micronaire, fiber length (2.5% and 50% span length) and uniformity ratio in NR-LPP, NR-HPP), CR 18 and CR-HPP).

Treatments	Seed-cotton Kg ha^{-1}	micronaire	50% span length	2.5% span length	Uniformity	Individual boll weight	Fiber % proportion
CR	3263 a**	3.72 a*	15.45 a	30.36	50.03 a	5.339 a**	38.614 a*
NRLPP	3435 a*	3.45 ab	14.9 ab	30.40	48.15 ab	5.033 a*	38.710 a*
NRHPP	2768 b	3.26 b	14.3 b*	29.75	47.26 b	4.470 b	37.527 b
CRHPP	3187 a*	3.77 a*	15.1 ab	29.86	49.76 a	5.114 a*	38.871 a**
LSD$_{(P: 0.05,0.01,0.001)}$	362, 520, 765	0.32, 0.45, 0.67	0.88, 1.27, 1.86	NS	2.31, 3.32, 4.89	055, 0.79, 1.16	0.93, 1.34, 1.97

* Non thinned out treatment of CR.
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.

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 mepiquat 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 fruits 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 marginal 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 Length 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). Bednarz *et al.* (2006a) found that as plant density increased, lint mass $boll^{-1}$, individual seed mass, and seed number $boll^{-1}$ decreased, while total seed surface area m^{-2} of land area increased, which resulted in increase lint yield m^{-2} of land area. They (Bednarz *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 system) were in agreement with some reports and not 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 experiments 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 Hearn (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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