

Impact of hedging on Washington Navel citrus trees

Taycir Grati*, Rachid Hellali, Salah Rezgui and Mehdi Ben Mimoun

NAT.43 Avenue Charles Nicole, City Mahrajene, 1082, Tunis, ISEP=BG 49 Avenue «13 Août Choutrana II, 2036 Soukra, Tunisia. *E-mail: taycir.grati@yahoo.fr

Abstract

The experiment consisted of hedging citrus trees of the variety “Washington Navel” with a planting density of 873 plants/ha. The hedge was 2.65 m high, 0.5 m wide on the upper part and 1.5 m on the lower part forming 10 degrees angle to the vertical and NE/SW orientation. The control tree was cut to a ball shape. Considering mean values of three years, hedging showed a high vegetative stretching (7.20 cm) while the control tree had a lengthening of 4.18 cm, with a growth rate of the spring shoots of 6.80 mm and 4.29 mm per day, respectively. As well, a larger spring leaf area was noted as compared to the control tree. This area was 366.55 cm² against 124.22 cm² by branch, respectively. In spite of a more severe pruning in the treatment, the fruit yield was near to that of the control (9.12 kg/tree) with a density of 873 trees/ha. No significant difference was noted for the total amount of chlorophyll between both sides of the hedge (South/East and North/West) for the non-bearing shoots (1.75 and 1.51 mg. g⁻¹ fresh weight, respectively) and bearing ones (1.57 and 1.51 mg/g fresh weight) contrarily to the control (non-bearing shoots 1.2 and 1.57 mg g⁻¹ fresh weight; bearing shoots 1.97 and 1.35 mg. g⁻¹ fresh weight). All stages of maturation occurred earlier in the treatment.

Key words: Citrus orchard, hedgerow orchard, radiation, high density planting, pruning, chlorophyll

Introduction

Area for citrus plantation is reducing in Tunisia and increased planting density could resolve this problem. However, high densities can lead to a reduction of sunshine into the foliage which could reduce productivity. Indeed, according to Hopkins (2003), photosynthesis, and therefore productivity, is closely dependent on a number of genetic and environmental factors, such as light and canopy shape. However, whether for trees in plantation (Ashton *et al.*, 1998; Richardson *et al.*, 2000) or isolated trees (Baraldi *et al.*, 1994; Combes *et al.*, 2000), a light gradient is observed between the high and peripheral parts of the canopy and the lower and central parts. The former regions (high and peripheral) appeared to receive more light in comparison to the latter ones suggesting that the space architecture of the axes affects light gradient.

Light interception in the hedge can vary depending on various parameters such as the hedgerow orientation (Palmer, 1989; Trentacoste *et al.*, 2015), its latitude (Olesen *et al.*, 2007), the shape of the hedgerow (Connor, 2006; Olesen *et al.*, 2007) and the porosity of the canopy (Trentacoste *et al.*, 2015). In addition, there is a correlation between the orientation of the hedgerow, its latitude and the season that affects light interception within the different levels of the hedge (Trentacoste *et al.*, 2015).

Several parameters are involved in light interception by the plant, such as pruning technique, foliar angle (Valladares and Pearcy, 1999; Fleck *et al.*, 2003), leaf organization in the shoots (Niklas, 1988; Takenaka, 1994) or the arrangement of the leaves within the canopy (Pearcy *et al.*, 2004). Willaume *et al.* (2004) noted that architecture in apple trees such as foliar density and the location of twigs in the crown influence significantly the capacities of light interception. Hence, Rabe (2004) suggested pyramidal forms for canopies with reduced spacing between planted rows contrarily to open shapes as the cup shape in orchards with low density.

Moreover, Tucker *et al.* (1994) have determined factors for citrus orchard that affect light interception in older trees, *i.e.*, spacing between planted rows, canopy angle, tree height and orientation of planted rows.

All these effects on light interception are not equally expressed according to the season. In the Mediterranean region, there are three important types of shoots produced in citrus trees during the growing season. The main type grows in late winter or early spring (spring shoots), and two additional types grow at the end of June (summer shoots) and in September (autumn shoots) (Loussert, 1989; Li *et al.*, 2010). The spring flush plays a determining role in the photosynthetic activity of the tree (more than 60 % of the new shoots) (Loussert, 1989). The spring flush is the most important for flower formation and flowering (Li *et al.*, 2010; Zhang *et al.*, 2011). The floral buds of sweet orange initiate their differentiation on spring shoots in March of the next year (Foster *et al.*, 2007). In most cases, only vegetative shoots are formed in the summer and autumn (Li *et al.*, 2010).

In this investigation we compared the effects of two shapes of canopies in citrus trees: a pyramidal shape forming a continuous hedge and a ball shape of isolated trees. These effects were assessed on the vegetative and fruit development as well as the total amount of leaf chlorophyll of the “Washington Navel” citrus variety.

Materials and methods

The study was carried out in the region of Cap Bon (37° N, 10° E) which is known for its citrus orchards, using the “Washington navel” variety of *Citrus sinensis*. The orchard was four years old at the beginning of the experiment. The density of plantation was 873 trees ha⁻¹ (3.5 x 3 m) oriented North-East. Two pruning techniques were tested: (i) A hedging forming a continuous pyramidal hedge, (ii) A cup pruning forming a ball shaped canopy.

These samples were considered as the control. For each type of pruning, measurements were performed during three years throughout the spring, summer and autumn development, on the 8th, 9th and 10th year of the orchard. However, only results related to the development of the spring flush which is the most important for photosynthetic activity and flower formation and flowering, are presented in this paper.

Hedging: According to Odier (1978, cited by Monney *et al.* 1993) the hedge must have a form allowing an efficient sunshine. The hedge is defined by its height (H), its width (l) and an angle (α : 10 to 20) (Fig.1).

The height was determined by the formula $H = L / \text{tg}(\alpha)$ where: $H = 2\text{m } 65\text{ cm}$ determined according to the latitude of the region and the required length L [L: width allowing the passage of mechanical machines ($L = 2\text{ m}$), α : latitude of the region (Cap Bon: $\alpha = 37^\circ$)].

The width of the base of the hedge (l) was determined by the formula: $l = E - L$, where: [E: spacing between rows ($E = 3.5\text{ m}$) and [L: width allowing the passage of mechanical machines ($L = 2\text{ m}$)]

Pruning consisted of cutting vegetative growth that developed beyond the desired shape. The vegetation which developed on the plantation line and between trees was slightly cut whereas extensions were not cut in order to obtain a continuous hedge with NE/SW orientation.

The ball shape: Control was aimed to obtain a low, solid and airy frame with a limited number of large branches (three to four). These criteria were achieved in a lowered ball with short trunk and foliage at low height.

Nine citrus trees of each pruning treatments were randomly divided into three groups. On the South-East (S/E) and North-

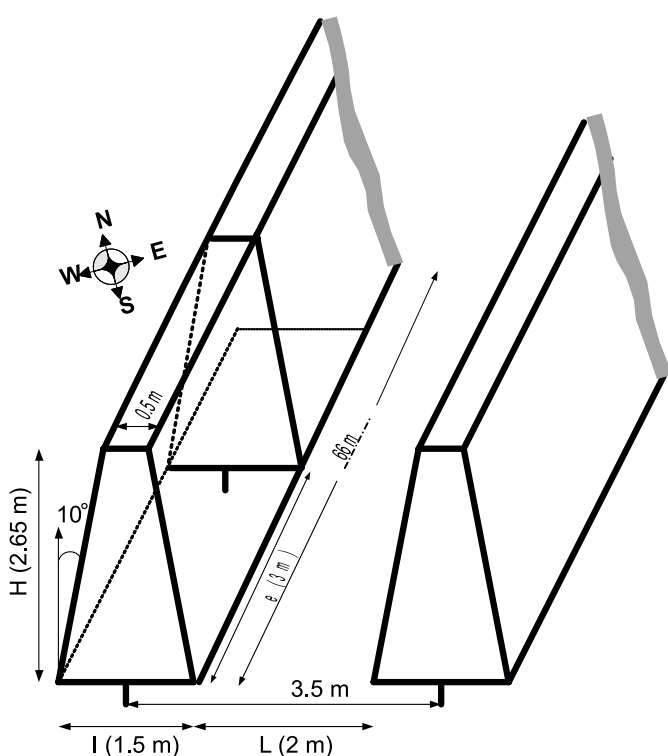


Fig. 1. Dimensions of the fruit-bearing hedge

West (N/W) sides of the tree, three branches at specific height were marked for future measurements (twice a month). This method enabled us to reconstitute a posteriori dynamics of installation of the spring growth for both types of treatments. For chlorophyll analysis, leaves from both fruiting and non-fruiting shoots on both sides of the canopy (S/E and N/W) were sampled.

Vegetative development: The average number of new shoots (ANS), the average elongation of new shoots (AES) and the average leaf area (ALA) were determined. The average number of new shoots (ANS_i) was regularly determined (twice a month at date t_i) for both control and treatment trees, as well as the average elongation of new shoots (AES_i). The shoots growth rate (twice a month at date t_i) was calculated as follow:

$$\text{SGR}_i = (\text{AES}_i - \text{AES}_{i-1}) / (t_i - t_{i-1})$$

Fruit development: Average number of blooming flowers (ANF), the average number of set fruit (ASF), and, after June drop, the average number of fruits (ANFr) per branch as well as the fruit yield per tree (AFY) and fruit size (S) [To better illustrate the quality of the sampled fruits, we classified fruits into two categories for each type of pruning: first category (S1: size > 75 mm) and second one (S2: size < 75 mm)] was determined. All along maturation process, we followed the different development stages of the fruits.

Total chlorophyll (TC): Total chlorophyll content (mg/g fresh weight) of bearing fruit shoots and non-bearing fruit shoots was determined according to the method of Mac Kinney (1941). Absorbance was determined using a "Bauch & Lambert" spectrometer at a wave length of 652 nm.

Statistical analysis: Variance analysis (ANOVA) using SAS software (Statistical Analysis System) was performed to compare the effect of pruning type (hedge or ball shape) on the vegetative, fruit development and total chlorophyll content taking into consideration parameters such as orientation of the side of tree (S/E and N/W) and year of measurement, as well as the interaction between these parameters.

Results and Discussion

The response of the tree using two pruning techniques was assessed. Different ways of tree vegetative growth organization could affect light interception and influence photosynthetic trend and carbon levels. These parameters were described using vegetative growth of trees and the fruit development.

Vegetative development

The statistical analysis showed a highly significant effect of the treatment ($P < 0.01$). The effect of pruning technique and canopy shape on the cumulative average number of spring shoots, on the average elongation of spring shoots and on the average foliar area of spring shoots is presented in Table 1.

Average number of shoots (ANS): Statistical analysis revealed two distinct groups. The first with the highest ANS (7.2) per branch represented the hedging effect, whereas the control formed the second group with an ANS of 4.18 per branch (Table 1). Furthermore, the treatment exhibited a significant difference between ANS oriented S/E and N/W, with 9.88 and 4.51, respectively. The values were higher than that found with

Table 1: Effect of pruning on vegetative growth

	ANS	AES (cm)	ALA (cm ²)
(Treatment)	**	**	**
Treatment	7.2 a	36.75 a	366.65 a
Control	4.18 a	18.59 b	124.22 b
(Treatment x Orientation)	**	**	*
Treatment (S/E)	9.88 ± 1.50	50.85 ± 7.42	437.73 ± 81.06
Treatment (N/W)	4.51 ± 0.84	22.63 ± 4.15	259.36 ± 69.68
Control (S/E)	4.25 ± 2.25	17.34 ± 3.40	92.93 ± 18.53
Control (N/W)	4.11 ± 0.75	19.83 ± 3.17	155.50 ± 28.01
(Treatment x Year)	*	ns	ns
Treatment (1 st year)	4.44 ± 0.78	27.87 ± 5.02	254.11 ± 48.32
Treatment (2 nd year)	6.94 ± 1.25	39.97 ± 10	450.21 ± 95.83
Treatment (3 rd year)	10.22 ± 1.79	42.38 ± 7.36	395.33 ± 92.90
Control (1 st year)	3.22 ± 0.56	12.09 ± 2.09	76.30 ± 16.23
Control (2 nd year)	4.61 ± 0.71	23.66 ± 4.19	171.48 ± 30.80
Control (3 rd year)	4.72 ± 0.49	20.01 ± 1.99	124.85 ± 19.61

Means within a column followed by different letters are significantly different ($P < 0.05$) (ns): no significant (*): significant variation ($P < 0.05$) (**): highly significant variation ($P < 0.01$) The ANOVA Procedure Tests t (LSD)

the control S/E and N/W, *i.e.*, 4.25 and 4.11 shoots, respectively (Table 1). There was also a significant interaction between the pruning type and the year on the average number of shoots / branch. The ANS increased significantly for the treatment as the years passed, contrarily to the control (4.44; 6.94; 10.22 and 3.22; 4.61; 4.72, respectively) (Table 1).

Average elongation of shoots (AES): Results indicated two significantly different groups. The first one presented an AES of 36.75 cm per branch and corresponded to hedging, whereas the control was associated to the second group with an AES of 18.59 cm (Table 1). Besides, the treatment in S/E side showed the highest AES (50.85 cm) compared to the N/W side (22.63 cm), whereas the control displayed values of 17.34 and 19.83 cm in the S/E and N/W sides, respectively (Table 1). There was no significant interaction between pruning type and the year for AES (Table 1).

Average leaf area (ALA): The higher ALA (366.55 cm²) per branch was represented by the treatment as compared to the control (124.22 cm²) (Table 1). Furthermore, the treatment resulted in higher average values for ALA in the S/E side compared to the N/W side (437.73 cm² and 259.36 cm², respectively). For the control, ALA values were 92.93 for the S/E side and 155.50 cm² for the N/W side (Table 1). Pruning type and year interaction was not significant (Table 1).

Shoot growth: The variation in number of growing shoots presented a bell-shaped curve for both control and treatment (Fig. 2). Significant differences were noted between cumulative number of shoots, with the highest value (9.88 per branch) observed for the treatment in the S/E side of the canopy (Table 1 and Fig. 2). Variations in spring shoots elongation showed a sigmoid-shaped growth for both control and treatment at S/E and N/W sides, with an exponential phase at the beginning of spring. The final shoot length of the hedging differed from the control with the highest value for the treatment in the S/E side of the canopy (50.85 cm per branch) (Table 1 and Fig. 3). Growth rates suggested a similar trend and are illustrated in Fig. 4. Increased growth rates during spring reached a maximum at the end of

February – beginning of March, then decreased to zero at the beginning of May. Greater significant differences between control and treatment for the maximum values of growth rate were noted. The maximum activity of shoots elongation (8.94 mm day⁻¹) was observed for the treatment (S/E) at the end of February against 4.66 mm day⁻¹ for N/W. Control showed a growth rate of 3.81 mm day⁻¹ and 4.67 mm day⁻¹ (S/E and N/W sides, respectively), independently of the years, suggesting that the final shoot length seems to be correlated to the average growth rate and duration of growing period. Statistical analysis put in evidence a positive effect of the treatment and orientation on the final shoots elongation, and thus on the elongation rate (Table 1).

The impact of the pruning and foliage shape and porosity of the canopy were significant on the vegetative development of the tree (Tucker *et al.*, 1991; Germana *et al.*, 2004). Hedging appeared to provide greater number of shoots and the higher shoot elongation and leaf area in comparison to the control. Several studies showed that the efficiency of interception of the light is largely dependent on the foliar density within the canopy (Robinson, 1997; Tustin *et al.*, 2001; Willaume *et al.*, 2004; Trentacoste *et al.*, 2015) and the shape of the hedge (Connor, 2006; Olesen *et al.*, 2007; Stéphan *et al.*, 2007 and Trentacoste *et al.*, 2015). Like all the species of the *Citrus* genus, Navels are evergreen trees enabling it to preserve a photosynthetic activity throughout the year (Jacquemond *et al.*, 2013; Zhang *et al.*, 2014). Some differences in the growth rate were also observed between both, ways of pruning in one hand and tree orientation on the other hand. In this study, growth rate seems to be a decisive factor explaining the differences in the final length of spring shoots. Massonnet (2004) reported the same conclusion for apple trees. Furthermore, the hedge on the S/E showed a higher growth speed and a more important cumulative number of shoots and final shoot length compared to the N/W side. These results would suggest that the orientation of the hedgerow can

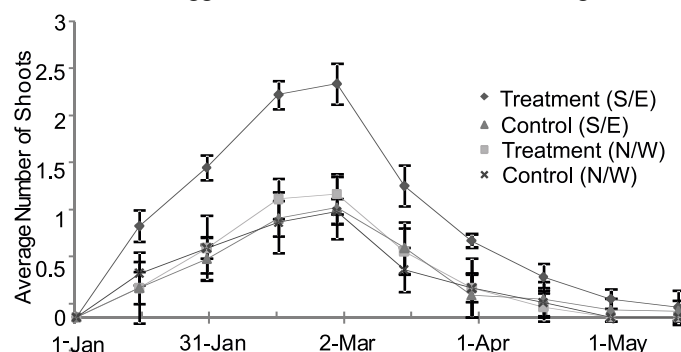


Fig. 2. Variation in the average shoot number as a function of time

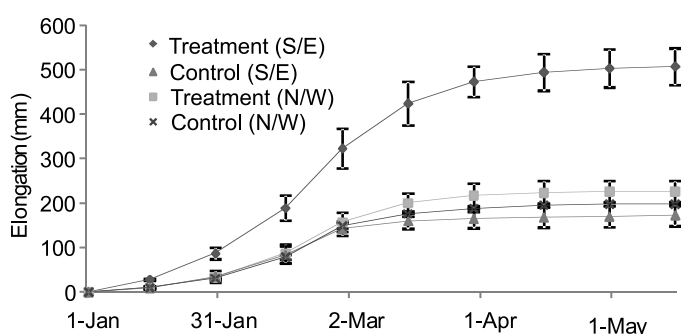


Fig. 3. Variation in average shoot length as a function of time

significantly influence light interception (Trentacoste *et al.*, 2015). Moreover, the obtained results indicated that NE/SW orientation affects light interception of the S/E side depending on the season. Indeed, during winter and on the equinoxes, the light interception on the sides decreases linearly with the depth of the canopy whereas during summer, there is only a slight variation on the sides for depth up to 2m ($H/L \leq 0.66$) and decreases linearly for more important depth. Light interception on the N/W side of the hedgerow takes place essentially during summer and on the equinoxes and it decreases gradually with the depth of the canopy. Moreover, the transmission of radiation from the sunlight is very sensitive to the orientation of the hedgerow and the structure of the foliage. The porosity of hedges however has little influence over the transmission of radiation for the N/S orientation. Wheaton *et al.* (1993) showed that the E/W orientation showed an increase of the radiation of 200 % during winter on the shaded side for a 30 % porosity. For the NE/SW orientation, the effect was intermediate. Cohen and Fuschs (1987), Cohen *et al.* (1987) and Trentacoste *et al.* (2015) recommended an appropriate orientation allowing optimized sunshine diffusion in inclined hedges. Photosynthesis and biomass production are under the influence of many environmental parameters especially light and canopy structure (Hopkins, 2003; Trentacoste *et al.*, 2015) in high-density plantings where leaves overshadow mutually. The shadow decreases the overall efficiency of light interception (Hopkins, 2003). Thus, shaded zones are more important in the ball shapes than in the hedge ones where the slope angle leads to a better light exposition, to enhance vegetative development in hedged shape.

Fruit development

Statistical analysis did not indicate significant effect of the treatment on the average number of flowers and fruit set (Table 2).

Average number of flowers (ANF): There was no significant effect of the type of pruning on the ANF per branch (Table 2). It was noted that the control had the higher ANF, precisely in the S/E side with 71.31 whereas the treatment had 51.07 flowers. No significant interaction between pruning type and the year was found (Table 2).

Average of set fruit (ASF): Significant differences for set

Table 2. Effect of pruning on fruiting

	ANF	ASF	ANFr	Yield/tree (kg)
(Treatment)	ns	*	ns	ns
Treatment	44.09 a	5.75 b	0.64 a	9.12 a
Control	57.09 a	8.63 a	0.76 a	10.51 a
(Treatment x Orientation)	ns	ns	ns	
Treatment (S/E)	51.07 ± 22.00	7.14 ± 3.89	0.96 ± 0.53	
Treatment (N/W)	37.11 ± 23.84	4.37 ± 4.86	0.63 ± 0.30	
Control (S/E)	71.31 ± 28.49	8.18 ± 3.57	0.74 ± 0.52	
Control (N/W)	43.26 ± 22.56	9.09 ± 3.15	0.55 ± 0.32	
(Treatment x Year)	ns	*	ns	ns
Treatment (1 st year)	39.94 ± 26.94	2.77 ± 0.75	0.49 ± 0.45	7.12 ± 2.3
Treatment (2 nd year)	48.39 ± 25.7	7.77 ± 1.98	0.78 ± 0.17	9.20 ± 3.0
Treatment (3 rd year)	44.94 ± 20.43	6.72 ± 1.13	1.11 ± 0.50	11.04 ± 3.5
Control (1 st year)	37.55 ± 20.65	9.78 ± 0.7	0.27 ± 0.25	8.00 ± 2.60
Control (2 nd year)	75.72 ± 31.53	6.66 ± 1.51	0.94 ± 0.82	13.06 ± 4.60
Control (3 rd year)	58.61 ± 22.91	9.47 ± 0.71	0.72 ± 0.25	10.50 ± 3.50

Means within a column followed by different letters are significantly different ($P < 0.05$) (ns): no significant (*): significant variation ($P < 0.05$) (**): highly significant variation ($P < 0.01$) The ANOVA Procedure Tests t (LSD)

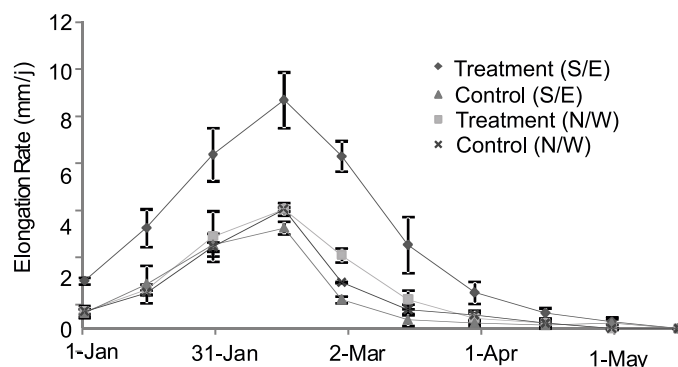


Fig. 4. Variation in elongation rate as a function of time

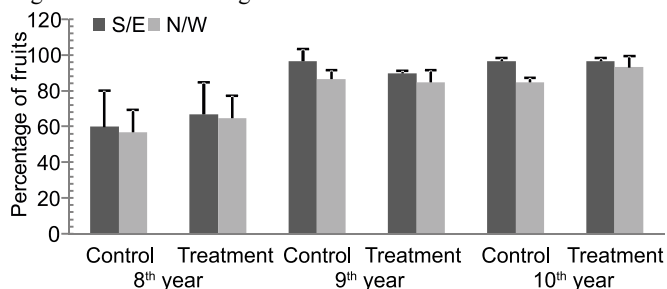


Fig. 5. Percentage of fruits with size > 75 mm

fruit per branch were observed for the control and hedged trees (Table 2). No significant difference between type of pruning and orientation interaction was found. However, the control resulted in the higher ASF in the N/W side *i.e.* 9.09 against 4.37 for the treatment (Table 2). We noted a significant difference between type of pruning and the year on the ASF (Table 2). Indeed, the hedging improved the ASF per branch through the years (2.77; 7.77; 6.72) as compared to control (9.78; 6.66; 9.47).

Average number of fruits (ANFr): There was no significant difference between type of pruning and control (0.76 and 0.64 per branch, respectively) as well as the interaction of treatment and orientation effect on the ANFr. Nevertheless, the treatment presented the highest value in the S/E side (0.96 fruit per branch) as compared to the control which gave only 0.74 fruits (Table 2). Interaction between pruning type and year wasn't significant on the ANFr (Table 2).

Average fruits yield (AFY): Statistical analysis didn't show significant difference as for the AFY for both types of pruning (treatment and control, *i.e.* 9.12 and 10.52 kg/tree, respectively). However, if considering that the trees of the treatment underwent a more severe pruning than the control, hence the canopy volume of the hedge pruned trees was smaller than the ball shaped trees, and taking into account that the final shape was not yet reached in the treatment, we can suggest that the AFY is relatively enhanced for the treatment (Table 2). There was no significant interaction between pruning type / year. However, fruits yield per tree increased during the three years of experimentation for the treatment (7.12; 9.2; 11.04 kg/tree) whereas the control showed an alternation in the fruits production (8; 13.06; 10.5 kg/tree) (Table 2).

Fruit size: Fruit size varied as the orientation

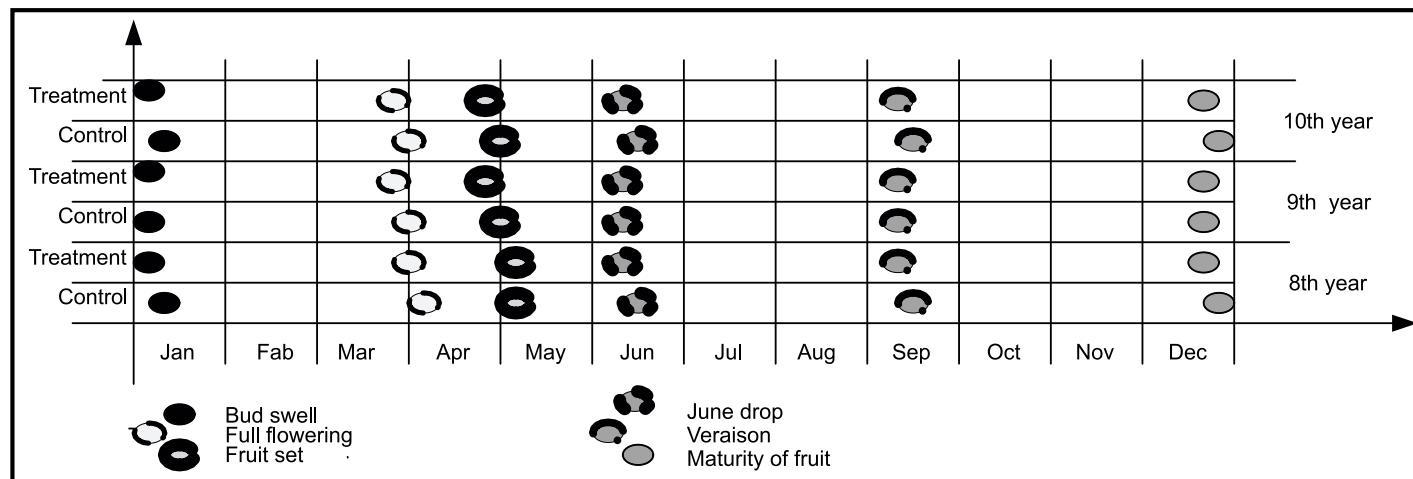


Fig. 6. Fruits development stages as influenced by treatments

changed for both kinds of pruning. Indeed, S/E side allowed more fruits of S1 size (> 75 mm). However, the difference of percentage of S1 and S2 (< 75 mm) fruits between both orientations was more emphasized in the control. The control showed a percentage of S1 fruits of 60 % in the S/E side against 57 % in the N/W side in the first year; in the second year this percentage reached 96 and 86 % respectively; during the third year values were 96.7 and 85 %, respectively. Thus, the difference between both orientations was 3, 10 and finally 11.7 %; whereas differences obtained with the treatment were 2, 5 and 3.4 % during the first, second and third year, respectively (Fig. 5).

Fruits development stages: The maturation of the fruits started earlier in the year in treatment than the control. The full flowering, fruit set, veraison and the maturity of the fruits occurred earlier for the treatment than the control (Fig. 6).

It is reported that tree productivity depends on the structure and growth of its aerial system (Lespinasse, 1977; Costes *et al.*, 2003). Increased level of photosynthetic activities appeared to be closely associated with higher percentage of soil covers with thick canopies in the orchards of citrus trees (ball shaped trees) and with a maximal foliar area index. Furthermore, when the canopy is inclined, light penetration is improved, which ensures a productivity all along the hedge (Cohen *et al.*, 1987). The mean number of fruits per branch, with reduced canopy volume of the tree, was not significant for conventional and hedging. Indeed, according to Grossman and Dejon (1998) the radiation increases the dry plant matter but the fruit production does not necessarily increase with the radiation increase. Besides, the treatment provided higher number of fruits, precisely in the S/E side of the tree. These results are consistent with the results presented by Tombesi and Cartechini (1986). Moreover, the fruit maturity in the treatment occurred earlier in the year than the control. This result could be ascribed to a better light interception in the hedge-shape trees than in the ball-shaped ones, which is in agreement with the results of Wheaton *et al.* (1993) and Rabe (2004). As in citrus trees, the best photosynthetic efficiency is reached with a PAR (Photosynthetically Active Radiation) of 30 %. However, light levels decrease below the optimum when diffusing at least at 100 cm inside the foliage (depending on the foliage density), with the creation of very shaded and dark (hence non-productive) zones (Rabe, 2004). Foliar density of the canopy turns out to be an essential parameter with regard to the

efficiency of light interception (Robinson, 1997; Tustin *et al.*, 2001). Hence, we can easily put in evidence the positive effect of a good sunlight on the fruits. Indeed, we observed better number of fruits and the fruit yield per tree in the treatment in spite of the decrease of the canopy volume as result of the relative severe pruning compared to the control. Fruits yield are dependent on the luminous microclimate inside the canopy, and subsequently on the total light interception (Jackson, 1980; Palmer, 1989; Robinson and Lakso, 1991). According to Lakso (1980), Robinson *et al.* (1983) and Awad *et al.* (2001), the lack of sunlight has a negative impact on the fruits yield. If we extrapolate, the fruits yield of the treatment (9.12 kg/tree) with a density of 873 trees ha⁻¹, it should be of 7961.76 kg ha⁻¹, whereas it should be 4376.32 kg ha⁻¹ for the control (10.52 kg/tree) with a density of 416 trees ha⁻¹; yet, this density is the most common in the regions of culture of citrus trees, with a ball-shaped canopy. Nevertheless, only a hedge shape is acceptable if we consider a higher density. Hopkins (2003) reported that the perfect canopy allows an optimal efficiency of light interception by modulating leaf area and taking into account leaf insertion angle, planting density and senescence of the oldest leaves. Besides, the economic advantage with a more suitable density would be represented by an enhanced yield (Rabe, 2004).

Total chlorophyll content (TC): Pruning did not show a significant effect on total chlorophyll content of non-bearing fruit shoots and bearing fruit shoots (Table 3). Orientation and type of pruning significantly affected chlorophyll content of non-bearing fruit shoots and bearing fruit shoots. The treatment showed a lesser difference of TC of non-bearing fruit shoots between both orientations S/E and N/W (1.75 and 1.51 mg. g⁻¹, respectively) than for the control (1.20 and 1.57 mg. g⁻¹, respectively). The treatment did not show any significant difference in TC of bearing fruit shoots between both orientations (S/E and N/W, *i.e.* 1.57 and 1.51 mg. g⁻¹, respectively). However, the control exhibited a significant difference between both orientations (*i.e.* 1.97 mg g⁻¹ for S/E side and 1.37 mg. g⁻¹ for N/W side). Total chlorophyll content of non-bearing fruit shoots and bearing fruit shoots was not affected by the interaction pruning type x year. Many functions such as photosynthetic activity, transpiration and the energy equilibrium inside the leaf are under the influence of the arrangement of leaves in the branch (Percy and Yang, 1996). Thus, the photosynthetic activity will depend on: 1) the amount of intercepted light, 2) the anatomy and 3) the biochemical reactions of the leaf (Roggy *et al.*, 2005). The photosynthetic capacity of

Table 3. Effect of pruning on total chlorophyll content

	Vegetative shoots (mg/g fw)	Fruits-bearing shoots (mg/g fw)
(Treatment)	ns	ns
Treatment	1.631 a	1.542 a
Control	1.390 a	1.666 a
(Treatment x Orientation)	*	**
Treatment (S/E)	1.750 ± 0.03	1.574 ± 0.02
Treatment (N/W)	1.510 ± 0.02	1.510 ± 0.02
Control (S/E)	1.208 ± 0.01	1.975 ± 0.02
Control (N/W)	1.572 ± 0.02	1.357 ± 0.40
(Treatment x Year)	ns	ns
Treatment (1 st year)	1.61 ± 0.12	1.53 ± 0.20
Treatment (2 nd year)	1.52 ± 0.15	1.43 ± 0.18
Treatment (3 rd year)	1.75 ± 0.20	1.65 ± 0.15
Control (1 st year)	1.38 ± 0.18	1.63 ± 0.20
Control (2 nd year)	1.30 ± 0.17	1.54 ± 0.15
Control (3 rd year)	1.48 ± 0.25	1.80 ± 0.22

Means within a column followed by different letters are significantly different ($P < 0.05$) (ns): no significant (*): significant variation ($P < 0.05$) (**): highly significant variation ($P < 0.01$) The ANOVA Procedure Test de Student-Newman-Keuls

the leaves can be predicted precisely using a combination of architectural and biochemical foliar parameters (Enriquez *et al.*, 1996; Reich *et al.*, 1999). It depends significantly on the amounts of chlorophyll and nitrogen in the leaf (Evans, 1989; Garnier *et al.*, 1999). Bailey *et al.* (2001) working on *Arabidopsis thaliana*, reported that the increase of luminous intensity depends on the thickening of the limb and on the increase of the number of chloroplasts because of the palissadic parenchyma distributed on different cellular layers. Chlorophyll content in this experiment was affected by the type of pruning and therefore by the tree shape. Indeed, the pyramidal shape showed no significant difference between both sides of the tree contrarily to the ball shape.

The trial of hedging citrus trees of the “Washington navel” variety suggested a positive effect on the chlorophyll amount, vegetative development and productivity, with a higher planting density of 873 plants ha⁻¹.

Acknowledgements

We thank member of arboriculture department of the “Institut National Agronomique” in Tunis for technical and scientific support. We thank members of “Office des Terres Domaniales” in Tunisia for their technical support.

References

- Ashton, P.M.S., L.P. Olander, G.P. Berlyn, R. Thadani and I.R. Cameron, 1998. Changes in leaf structure in relation to crown position and tree size of *Betula papyrifera* within fire-origin stands of interior cedar-hemlock. *Canadian Journal Botany*, 76: 1180-1187.
- Awad, M.A., P. Wagenmakers and A. de Jager, 2001. Effects of light on flavonoid and chlorogenic acid levels in the skin of ‘Jonagold’ apples. *Sci. Hort.*, 88: 289-298.
- Bailey, S., R.G. Walters, S. Jansson and P. Horton, 2001. Acclimation of *Arabidopsis thaliana* to the light environment: the existence of separate low light and high light responses. *Planta*, 213: 794-801.
- Baraldi, R., F. Rossi, O. Facini, F. Fasolo, A. Rotondi, M. Magli and F. Nerozzi, 1994. Light environment, growth and morphogenesis in a peach tree canopy. *Physiologia Plantarum*, 91: 339-345.

- Cohen, S. and M. Fuschs, 1987. The distribution of leaf area, radiation photosynthesis and transpiration in a shamouti orange hedgerow orchard. *Agr. For. Meteorol.*, 40: 123-144.
- Cohen, S., M. Fuschs, S. Moreshet and Y. Cohen, 1987. The distribution of leaf area, radiation photosynthesis and transpiration in a shamouti orange hedgerow orchard. *Agr. For. Meteorol.*, 40: 145-162.
- Combes, D., H. Sinoquet and C. Varlet-Grancher, 2000. Preliminary measurement and simulation of the spatial distribution of the Morphogenetically Active Radiation (MAR) within an isolated tree canopy. *Annals Forest Science*, 57: 497-511.
- Connor, D.J. 2006. Towards optimal designs for hedgerow olive orchards. *Aust. J. Agric. Res.*, 57: 1067-1072.
- Costes, E., H. Sinoquet, J.J. Kelner and C. Godin, 2003. Exploring within-tree architectural development of two apple tree cultivars over 6 years. *Annals of Botany*, 91: 91-104.
- Enriquez, S., C.M. Duarte, K. Sand-Jensen and S.L. Nielsen, 1996. Broad-scale comparison of photosynthetic rates across phototrophic organisms. *Oecologia*, 108: 197-206.
- Evans, J.R. 1989. Photosynthesis and nitrogen relationships in leaves of C3 plants. *Oecologia*, 78: 9-19.
- Fleck, S., U. Niinemets, A. Cescatti and J.D. Tenhunen, 2003. Three-dimensional lamina architecture alters light-harvesting efficiency in *Fagus*: a leaf-scale analysis. *Tree Physiology*, 23: 577-589.
- Foster, T.M., A.N. Seleznyova and A.M. Barnett, 2007. Independent control of organogenesis and shoot tip abortion are key factors to developmental plasticity in kiwifruit (*Actinidia*). *Ann Bot.*, 100(3): 471-481.
- Garnier, E.J., L. Salager, G. Laurent and L. Sonié, 1999. Relationships between photosynthesis, nitrogen and leaf structure in 14 grass species and their dependence of expansion. *New Phytologist*, 143: 119-129.
- Germana, C., A. Continella and E. Tribulato, 2004. Pruning influence on physiological and productive behaviour of young « Lane Late » orange Trees. *Proc. Int. Soc. Citriculture*, 1: 291-294.
- Grossman, Y.L. and T.M. Dejon, 1998. Traing and pruning system effects on vegetative growth potential light interception, and cropping efficiency in peach trees. *J. Amer. Soc. Hort. Sci.*, 123(6): 1058-1064.
- Hopkins, G.W. 2003. *Physiologie Végétale*. Ed. De Boeck Université Bruxelles.
- Jackson, J.E. 1980. Light interception and utilization by orchard systems. *Hort. Rev.*, 2: 208-267.
- Jacquemond, C., F. Curk and M. Heuset, 2013. Les clémentiniers et autres petits agrumes. Ed. Quea Cirad, Infremer, Inra, Irstea.
- Lakso, A.N., J.N. Wünsche, J.W. Palmer and L. Corelli-Grappadelli, 1999. Measurement and modeling of carbon balance of the apple tree. *HortScience*, 34: 1040-1047.
- Lespinasse, J.M. 1977. La conduite du Pommier. I- Types de fructification. Incidence sur la conduite de l’arbre. Ed. I.N.V.U.F.L.E.C. Paris.
- Li, Z.M., J.Z. Zhang, L. Mei, X.X. Deng, C.G. Hu and J.L. Yao, 2010. PtSVP, an SVP homolog from trifoliolate orange (*Poncirus trifoliata* L. Raf.), shows seasonal periodicity of meristem determination and affects flower development in transgenic *Arabidopsis* and tobacco plants. *Plant Mol Biol.*, 74(1-2): 129-142.
- Loussert, R. 1989. Les agrumes Vol. 1. Col. Technique et Production Agricole. Ed. Scientifique Universitaire Mkalles Beyrouth.
- Massonnet, C. 2004. Variabilité architecturale et fonctionnelle du système aérien chez le pommier (*Malus domestica*, Borkh) : comparaison de quatre cultivars par une approche de modélisation structure-fonction. [Ph.D. Thesis.]. Ecole Nationale Supérieure Agronomique de Montpellier., 184 pp.
- Monney, P., C.H. Blasser, A. Widmer and Ch. Krebs, 1993. Les systèmes de verger. *Rev. Suisse Vitic., Arboric., Hort.* 25(2): 87-97
- Niklas, K.J. 1988. The role of phyllotactic pattern as a “developmental constraint” on the interception of light by leaf surfaces. *Evolution*, 42: 1-16.

- Olesen, T., S. Morris and L. McFadyen, 2007. Modelling the interception of photosynthetically active radiation by evergreen subtropical hedgerows. *Aust. J. Agric. Res.*, 58: 215-223.
- Palmer, J.W. 1989. Canopy manipulation for optimum utilization of light. In: *Manipulation of Fruiting*. C.J. Wright (Ed.). Butterworths, London, pp 245-262.
- Palmer, J.W. 1989. The effects of row orientation, tree height, time of year and latitude on light interception and distribution in model apple hedgerow canopies. *J. Hort. Sci.*, 64(2): 137-145.
- Pearcy, R. and W.W. Yang, 1998. The functional morphology of light capture and carbon gain in the Redwood forest understorey plant *Adenocaulon bicolor* Hook. *Functional Ecology*, 12: 543-552.
- Pearcy, R.W., F. Valladares, S.J. Wright and E.L. Paulis, 2004. A functional analysis of the crown architecture of tropical forest *Psychotria* species: do species vary light capture efficiency and consequently in carbon gain and growth?. *Oecologia*, 139: 163-177.
- Rabe, E. 2004. Citrus tree spacing and tree shape: concepts, effect on early production profile and fruit quality aspects - an overview. *Proc. Int. Soc. Citriculture*, 1: 297-301.
- Reich, P.B., D.S. Ellsworth, M.B. Walters, J.M. Vose, C. Gresham, J.C. Volin and W.D. Bowman, 1999. Generality of leaf trait relationships: a test across six biomes. *Ecology*, 80: 1955-1969.
- Richardson, A.D., G.P. Berlyn, P.M.S. Ashton, R. Thadani and I.R. Cameron, 2000. Foliar plasticity of hybrid spruce in relation to crown position and stand age. *Canadian Journal Botany*, 78: 305-317.
- Robinson, T.L. 1997. Interaction of tree form and rootstock on light interception, yield and efficiency of 'Empire', 'Delicious' and 'Jonagold' apple trees trained to different systems. *Acta Horticulture*, 451: 427-436.
- Robinson, T.L. and A.N. Lakso, 1991. Bases of yield and production efficiency in apple orchard systems. *J. Amer. Soc. Hort. Sci.*, 116: 188-194.
- Robinson, T.L., E.J. Seeley and B.H. Barritt, 1983. Effect of light environment and spur age on 'Delicious' apple fruit size and quality. *J. Am. Soc. Hort. Sci.*, 108: 855-861.
- Roggy, J.C., E. Nicolini, P. Imbert, Y. Caraglio, A. Bosc and P. Heuret, 2005. Links between tree structure and functional leaf traits in the tropical forest tree *Dicorynia guianensis* Amshoff (Caesalpinaceae). *Annals of Forest Science*, 62: 1-12.
- Stephan, J., T.H. Sinoqueth, N. Donès, N. Haddad, S. Talhouk and P.E. Lauri, 2007. Light interception and partitioning between shoots in apple cultivars influenced by training. *Tree Physiology*, 28: 331-342.
- Takenaka, A. 1994. Effects of leaf blade narrowness and petiole length on the light capture efficiency of a shoot. *Ecological Research*, 9: 109-114.
- Tombesi, A. and A. Cartechini, 1986. L'effetto dell'ombreggiamento della chioma sulla differenziazione delle gemme a fiore dell'olivo. *Riv. Ortoflorofruttic. Ital.*, 70: 277-285.
- Trentacoste, E.R., D.J. Connor and M. Gómez-del-Campo, 2015. Row orientation: Applications to productivity and design of hedgerows in horticultural and olive orchards. *Scientia Horticulturae*, 187: 15-29.
- Tucker, D.P.H., T.A. Wheaton and R.P. Muraro, 1991. Citrus Tree Spacing and Pruning. Copyright University of Florida. *Institute of Food and Agriculture Sciences*, SP 74.
- Tucker, D.P.H., T.A. Wheaton and R.P. Muraro, 1994. *Citrus Tree Spacing*. *Hort. Soc. Fact Sheet* HS-144.
- Tustin, D. S., W.M. Cashmore and R.B. Bensley, 2001. Pomological and physiological characteristics of slender pyramid central leader apple (*Malus domestica*) planting systems grown on intermediate vigour, semi-dwarfing, and dwarfing rootstocks. *New Zealand Journal of Crop Horticultural Science*, 29: 195-208.
- Valladares, F. and R.W. Pearcy, 1999. The geometry of light interception by shoots of *Heteromeles arbutifolia*: morphological and physiological consequences for individual leaves. *Oecologia*, 121: 171-182.
- Wheaton, T.A., J.D. Whitney, D.P.H. Tucker and W.S. Castel, 1993. *Management of closely Spaced Trees*. University of Florida: John T. Woeste, Dean.
- Willaume, M., P.E. Lauri and H. Sinoquet, 2004. Light interception in apple trees influenced by canopy architecture manipulation. *Trees*, 18: 705-713.
- Zhang, J.Z., X.Y. Ai, L.M. Sun, D.L. Zhang, W.W. Guo, X.X. Deng and C.G. Hu, 2011. Transcriptome profile analysis of flowering molecular processes of early flowering trifoliolate orange mutant and the wild-type [*Poncirus trifoliata* (L.) Raf.] by massively parallel signature sequencing. *BMC Genomics*, 12(1): 12-63.

Received: January, 2016; Revised: April, 2016; Accepted: April, 2016