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Cone yield evaluation of a grafted *Pinus pinea* L. trial

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Abstract. Grafted stone pine plantations for cone production could be an interesting alternative on low quality agriculture lands, as they display various advantages compared to the traditional forest harvesting: the possibility to use more productive genotypes, early bearing, easily harvesting, etc. Some grafted experiences with *P. pinea* have already been done, mainly focused on elucidating the relevance of environmental factors and in the selection of the best productive genotypes; however the productive information is still scanty. With a view to go into the species´ agronomical potential knowledge in depth, in 2008 a grafted trial was planted at IRTA's Torre Marimon station (Caldes de Montbui, Spain). In 2010 an irrigation essay was started in order to study the effect of different water regimes on the strobili induction and productive responses. The first results show an early production onset on production, from barely 50 flowers/ha in 2008 to more than 3,500 in 2011. The first significant cone yield was registered in 2011, with 840 $kg \cdot ha^{-1}$. Concerning water supply, preliminary results show in the irrigated trees a lower fruit mortality on the second development year than in the control (7% against 20%, in 2010) and a higher floral induction (14 flowers/tree against 10, in 2011) . Further results in the coming years will allow to evaluate the productive potential of this kind of plantations.

Keywords. Stone pine – Pine nut – Orchard management – Irrigation.

Evaluation productive d'une plantation greffée de* Pinus pinea *L.

Résumé. *Les plantations greffées de* Pinus pinea *peuvent constituer une intéressante alternative pour les terrains agricoles de basse qualité car présentant divers avantages en comparaison à la gestion forestière traditionnelle : possibilité d'utiliser des génotypes plus productifs, rapide entrée en production, facilité de récolte, etc. Diverses expériences de* P. pinea *greffé ont été déjà faites, principalement orientées à déterminer l'importance des facteurs environnementaux et à sélectionner des génotypes plus productifs. Cependant, l'information productive est plutôt rare. Afin d'approfondir les connaissances sur le potentiel agronomique de l'espèce, une plantation de* P. pinea *greffé fut établie en 2008 à l'IRTA Torre Marimon (Caldes de Montbui, Espagne). En 2010 un essai d'irrigation démarra dans l'objectif d'étudier l'effet de différents régimes hydriques pour l'induction florale et la réponse productive. Les premiers résultats montrent une rapide entrée en production, passant de 50 fleurs/ha en 2008 jusqu'à plus de 3500 en 2011. La première production significative de cônes eut lieu en 2011, avec 840 kg/ha. Concernant l'apport hydrique, les résultats préliminaires montrent une plus faible mortalité des cônes de deuxième année (7%* versus *20%, en 2010) et une plus nombreuse induction florale (14 fleurs/arbre* versus *10, en 2011) des arbres irrigués par rapport aux arbres témoins. Le suivi de cette expérience permettra d'évaluer plus précisément le potentiel productif de ce type de plantations.*

Mots-clés. *Pin pignon – Pignon – Gestion des vergers – Irrigation.*

I – Introduction

In spite of the high commercial value of its edible kernels, the Mediterranean stone pine still remains a genuine forest species. At present, the virtually total commercial cone yield is still harvested from natural or naturalised forests (Mutke *et al.*, 2000). Grafted plantations for cone production could be an interesting alternative on low quality agriculture lands. These plantations display various advantages compared to the traditional forest harvesting: early bearing, the possibility to use more productive genotypes and more adapted rootstocks to the soil, easily harvesting, better control against cone pillage, etc.

Some grafted plantations and trials with stone pine have already been done; however their productive information is still scarce. The oldest correspond to reforestations transformed by grafting. However, their cone yield evaluation was discontinuous and consequently provided imprecise data. One of the first documented experiences in Spain took place in the eighties (Catalan, 1990). More recently, experimental clonal orchards have been established since early nineties (Mutke *et al.,* 2000), mainly focused on elucidating the relevance of environmental and genetic factors for seed-yield quantity and quality (Mutke *et al.,* 2003; Mutke *et al.,* 2005a; Mutke *et al.,* 2007). With a view to go further in the study on the species' agronomical potential, a grafted *P. pinea* trial was planted in 2008 at IRTA's Research Station of Torre Marimon, near Barcelona.

Stone pine has a strong masting habit, which entails a very irregular fruitfulness in natural stands (Mutke *et al*., 2005b). Thus, a particular objective of this trial is to assess the effect of watering in floral induction, cone survival throughout the three-year development cycle, and in seed-yield quantity and quality. In other words, how alternate bearing is affected by watering.

II – Material and methods

1. Site description and plant material

The trial plot is located at IRTA's station Torre Marimon (Caldes de Montbui, Barcelona), at 2º 10' E, 41º 37' N and 160 m a.s.l. on the Pre-littoral Depression. The soil has a sandy texture with a clay horizon in the middle of the profile, low fertility and a lightly alkaline pH. Average annual temperature is 14.9ºC, with absolutes from –8.6 to 39.7 ºC (2000-2010). The average annual rainfall is 624 mm (1991-2000) and ranges from 472 to 954 mm. The climate is Nemoral oromediterranean in transition with Subnemoral Mediterranean, according to the Phytoclimatic Atlas of Spain (Allué Andrade, 1990).

The trial was established in spring 2008; 96 grafts were planted in a 6 x 6 m setting, thus the plot occupies 0.35 ha. Plants had been produced in 2003 by cleft grafting on seed-grown rootstocks of *P. halepensis* (heteroplastic grafts) stone pine scions collected from a group of 10 trees (from Catalonia Littoral provenance region) and remained in nursery for five years, stocked in very limiting conditions. Prior to the plantation, a soil preparation was carried out, including manuring and deep-plowing with a ripper. Drip irrigation was installed and weed competence was controlled.

2. Irrigation experiment

For the design of the irrigation trial, the results of previous studies have been taken into account. Water stress seems to be the most notable limiting factor in stone pine cone-yield (Mutke *et al.*, 2005b) and there is a correlation of rainfall at the end of shoot elongation (June rainfall) with shoot length and flower bearing in the next year (Mutke *et al*., 2003). According to these statements, the growing season has been divided in 3 periods in spring, early summer and late summer (Table 1), considering physiological processes involved, and irrigation treatments have been established considering different application periods: irrigation treatment 1 (T1) covers periods 1 and 2, and irrigation treatment 2 (T2) only covers the spring period 1 (Table 2). Outer rows of the trial constitute a control treatment, only watered in extreme drought events. Water supply (difference between rainfall and crop evapotranspiration of the previous week) is calculated according to rainfall and reference evapotranspiration (ETo) data registered by the Torre Marimon weather station. Crop evapotranspiration (ETc) is defined as the combined water vapour leaving the system by evaporation from soil and plant surfaces, which is calculated by multiplying ETo by a crop coefficient, Kc (White and Fisher 1985; Allen *et al*., 1998).

Table 1. Periods of the growing season and physiological processes that will be affected by irrigation treatments

Period	Dates *	Processes involved	
Period 1	April 1 – May 31	Spring shoot elongation 2nd year cone growth 3rd year cone growth	Secondary growth Flowering and pollination
Period 2	June 1 – July 31	Terminal buds differentiation Fertilisation Occasional summer shoot growth	Needle growth Secondary growth (final) 3rd year cone growth (final)
Period 3	August 1 – September 31	Needle growth (final) Occasional summer shoot growth	Embryo development

*Dates are approximate and must be corrected according to the year's phenology.

Table 2. Definition of the irrigation treatments

Irrigation treatment	Period 1	Period 2	Period 3
T1	100% [P-ETc]	100% [P-ETc]	*
T2	100% [P-ETc]	*	*
Control	*	*	*

*Only watered in extreme drought events. P: rainfall; ETc: crop evapotranspiration.

The trial design was on randomized complete blocks, with 3 repetitions and 2 trees per observation. The plantation began to be watered in 2009, and the water supply was 64 litres·tree^{-1}·week^{-1}, from April until August. In 2010 the irrigation system in lateral rows (control) was stopped; the rest of the trail was irrigated homogeneously with 64 litres·tree^{-1}·week^{-1} from June to August. In 2011 the irrigation treatments have been properly applied in the trail for the first time: 115.6 m^{3}·ha^{-1} of water was supplied on the T1 and 55.6 m^{3}·ha^{-1} on the T2 (Fig. 1). These quantities belong to a young plantation with 5% of canopy cover.

3. Measurements

Since plantation, several variables are measured at individual tree level: stem diameter above the graft union (used as covariate to adjust individual cone yield); crown projection (used to know the plant cover, variable needed in irrigation calculations); phenology of shoot and flower development, used to adjust beginning and end dates of the irrigation periods and also to detect the presence of summer shoots and second female flowering (polycyclic growth); cone cohorts have been monitored from initial female strobili number until the total number of ripe cones. Size, weight and number of seeds of each individual cone, seed yield (kg) and seed output are measured only in monitored trees (two trees per treatment and replication, i.e. a total of 18 trees).

III – Results and discussion

1. Onset on production

The first results of the trial show an early onset on production of trees, from barely 50 strobili/ha in 2008 to more than 3,500 produced in 2011 (Fig. 2). The first significant female flowering (with around 1,900 strobili/ha) took place in 2009, and its corresponding cone yield, in 2011 (4 years after planting). First male flowering appeared in 2011 (4 years after planting), but in low intensity. However, lateral pollination from surrounding adult trees guaranteed cone setting since the first flowering.

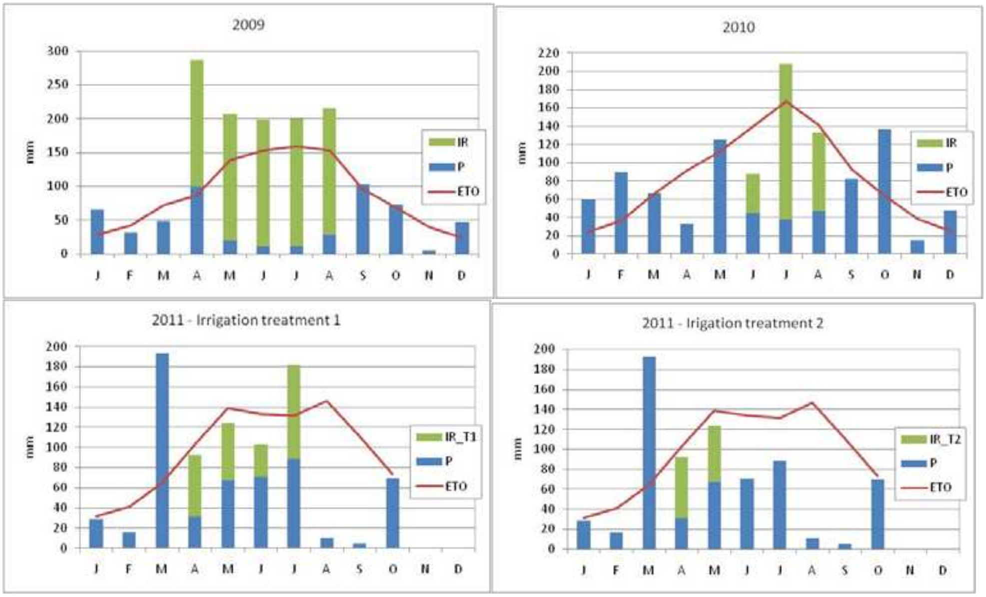

Fig. 1. Distribution of rainfall, evapotranspiration and water supplied since the beginning of the experience (IR: irrigation; P: rainfall; ETo: reference evapotranspiration).

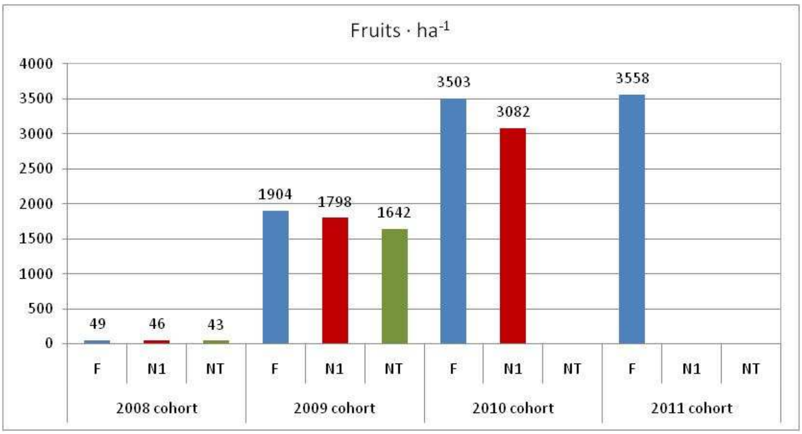

Fig. 2. Evolution of the successive reproductive cohorts (F: number of pollinated conelets; N1: number of one-year old cones; NT: total number of ripe cones, corresponding to the fruit evolution of three consecutive years).

The consecutive yield variables along the pathway from initial number of female buds up to the cone and seed yield are shown in Table 3. Concerning the first representative cone yield (2009 cohort), cone survival throughout the tree years (NC/IF) was about 76%; 290 kg of sound cones were harvested in the trail, which would be equivalent to 839 kg·ha^{-1}; the mean tree yield (PC/96) was 3.0 kg·tree^{-1} and the mean cone weight (PC/NC) 0.58 kg·cone^{-1}.

Table 3. Successive cone and seed yield parameters of the reproductive cohorts (total plot size 96 trees)

Cohort	IF	F	N0	N1	NT	NC	PC	PP
2008	-	17	17	16	15	15	3.7	0.8
2009	660	647	637	623	569	504	290.1	
2010	1214	1192	1068	1051				
2011	1240	1233	1038					

IF – initial female conelets number; F: number of pollinated conelets; N0: number of cones surviving the first summer; N1: number of one-year old cones; NT: total number of ripe cones; NC: number of sound cones; PC: cone yield (kg); PP: seed yield (kg).

2. Effects of watering

Concerning the effects of water supply only preliminary results have been arisen. Results of 2011 cone yield (Table 4) show a significant irrigation effect on the mean individual cone yield (4 kg·tree^{-1} in T1 against 1.9 in control), and also on the mean cone weight (616 g·cone^{-1} in T1 against 536 in control). However, according to the 2011 harvest data, the prolongation of the water supply until half-end of July does not show a significant cone yield increment, nor an individual cone weight increase.

Table 4. Analysis of variance for 2011 mean cone yield and mean cone weight

Irrigation treatment	Mean cone yield (kg·tree^{-1})	Mean cone weight (kg·cone^{-1})
T1	4.0a	0.616a
T2	3.4a	0.592a
Control	1.9b	0.536b
Significance	***	*

Duncan (α=0.05); *: significant at P<0.05%; ***: significant P<0.001%. Same letter indicates no significant differences between treatments.

Extrapolating the mean tree yield into yield per hectare, we would have obtained 509, 1056, 833 kg·ha^{-1} in treatment control, treatment 1 and treatment 2 respectively (Table 5). Even in control treatment, the cone yield would be higher than 500 kg·ha^{-1}. The average production in Spanish natural adult stands ranges from 200-600 kg·ha^{-1} year. The average yield from data recorded in public forests of Valladolid province (Northern Inland Plateau) from 1960 to 2000 is 193 kg·ha^{-1} (Mutke *et al.*, 2005b). The higher yield achieved in this trial is not only due to the irrigation effect; other factors are involved: grafted plants, site preparation, canopy illumination, herbaceous competition control, mild climate, etc. But, in 2011, a higher floral induction in irrigated trees against those without water supply was significantly detected (14 flowers·tree^{-1} against 10 flowers·tree^{-1}; P<0.001).

Table 5. Yield variables for the different irrigation treatments

Yield variable	Control	T 1	T 2
Mean tree yield (kg·tree^{-1})	1.9	4.0	3.4
Sound cone yield (kg·ha^{-1})	509	1,056	833
Estimated seed yield (kg·ha^{-1})† (20% of cone weight)	101.7	211.2	166.5
Estimated unshelled seed yield (kg·ha^{-1})† (5% of cone weight)	25.4	52.8	41.6

†The evaluation of cone and seed variables of the first cone yield is currently in progress.

Table 6. Analysis of variance for 2011 average individual flower number

Treatment	Average individual flowers number (flowers·tree^{-1})
Irrigated	13.92a
Control (non-irrigated)	9.96b
Significance	***

Duncan (α=0.05); ***: significant at P<0.001%. Same letter indicates no significant differences between treatments.

3. Water requirements estimation

Average monthly data of precipitation and ETo from the Torre Marimon weather station (period 1991-2010) are shown in Fig. 3. From these data, ETc, water deficit and water supply have been calculated (Table 7). These data show that months with water deficit correspond to the 3 periods in which the growing season has been divided. Thus, it is estimated that average water requirements for compensating the water deficit in our environmental conditions are 136 m^3 ha^{-1} $year^{-1}$ for treatment 1 and 35 $m^3 \cdot ha^{-1} \cdot year^{-1}$ for treatment 2. These values refer to a 5% canopy cover. For a 50% of canopy cover, the theoretical average water supply would be around 1,300-1,400 $m^3 \cdot ha^{-1} \cdot year^{-1}$. It is considered that more than 50% canopy covers are not recommended for this kind of plantations, in order to maintain a proper canopy illumination and to guarantee floral induction. Anyway, these are low amounts of water supply compared with other nut crops, like almond tree, which annual water demand is calculated around 2,000 $m^3 \cdot ha^{-1} \cdot year^{-1}$ in a regulated deficit irrigation scheduling (Girona *et al.*, 2005).

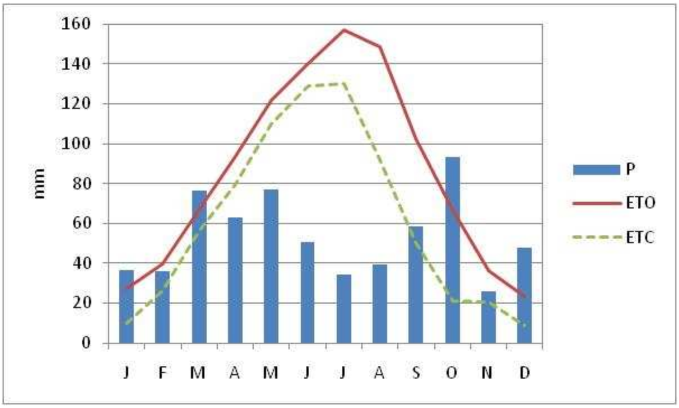

Fig. 3. Average distribution (1991-2010) of precipitation and evapotranspiration in the trial plot (P: rainfall; ETo: potential evapotranspiration; ETC: crop evapotranspiration).

Table 7. Calculation and distribution of water requirements

	P (mm)	ETo (mm)	Kc	ETc (mm)	P-ETc (mm)	WS ($m^3 \cdot ha^{-1}$)	Irrigation period	Irrigation treatment
Jan	36.3	27.5	0.35	9.6	26.7			
Feb	35.7	39.5	0.66	26.1	9.7			
Mar	76.3	67.3	0.84	56.5	19.8			
Apr	63.2	93.4	0.85	79.4	**-16.1**	12.5	Period 1	T1, T2
May	76.8	121.9	0.9	109.7	**-32.9**	22.5	Period 1	T1, T2
Jun	50.6	140.0	0.92	128.8	**-78.5**	46.1	Period 2	T1
Jul	34.1	157.0	0.83	130.3	**-96.2**	55.2	Period 2	T1
Aug	39.3	148.5	0.62	92.1	**-52.8**	31.4	Period 3	
Sep	58.7	102.7	0.49	50.3	8.4		Period 3	
Oct	93.5	66.9	0.32	21.4	72.1			
Nov	25.7	36.6	0.56	20.5	5.2			
Dec	47.9	23.5	0.38	8.9	39.0			

P: rainfall; ETo: reference evapotranspiration; Kc: crop coefficient; ETc: crop evapotranspiration; WS: water supply

The productive potential of this kind of plantations is expected to be evaluated by further results, establishing a guide for maximizing production and also for cone quality improvement.

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