STONE PINE ORCHARDS FOR NUT PRODUCTION: WHICH, WHERE, HOW?

The Mediterranean stone pine *Pinus pinea* produces the genuine pine nuts or "pignoli" used in Mediterranean and Arabian cuisine. Due to their supreme quality, they achieve higher prices than lower-quality surrogates like seeds from the Chinese *Pinus koraiensis*. On the Iberian Peninsula alone, stone pine covers more than 550,000 ha, and Spain and Portugal are the main pine-nut producing countries. Although stone pine, a native or at least protohistoric archaeophyte in most Mediterranean countries, is said to have been 'cultivated' since the Neolithic, actually hardly any effort seems to have been made for its proper domestication as nut crop (or at least to have achieved it): there are no defined cultivars, but nearly the whole current stone pine nut production is still harvested from forest stands where no cultivation techniques are applied except seeding or planting of new stands, thinnings for stand density regulation and some pruning in the lower or inner crown to ease manual harvesting or, historically, for fuel wood (Mutke et al., 2000a). Even the small pine groves or isolated border trees so typical of Mediterranean rural landscapes are usually seed-grown without known pedigree.

But the interesting market prices for pine nuts and the crisis of traditional rainfed crops in Mediterranean countries has drawn in the last years the attentions to Stone pine as an alternative woody crop on farmland. In farmland afforestations after the CAP reform in 1992, stone pine has been widely used for combining public subsidies with the expectation of future cone production (Mutke et al., 2000b; ANSUB, 2006). Private initiatives have promoted intensively managed stone pine plantations for pine nut production not only in the Mediterranean area (especially in Portugal), but even in several overseas countries like Australia or even Guatemala. In the last decade, cone gathering is increasingly made by harvesting machines, overcoming the shortage of skilled labour for the dangerous pine climbing for cone dropping.

CULTIVAR SELECTION FOR GRAFTED PLANTATIONS

In Italy, Portugal and Spain, research on grafting techniques and on clonal selections has been undertaken aiming the improvement and standardizing of pine nut production in specific plantations or under agroforestry systems (Baudín, 1967; Magini & Giannini, 1971; Catalán, 1990; Prada et al., 1997; Mutke et al., 2000a; Castaño et al., 2004).

Since the early nineties, several grafted clonal trials have been established in Spain within the framework of regional and national research programmes for the characterization of the crop and the tested genotypes, elucidating the relevance of genetic and environment factors for seed-yield quantity and quality (Mutke 2005). In several analysed trials, the degree of genetic determination for average annual cone yield (kg/tree) was estimated in 15-38%, resulting in an expected genetic gain of 12-39% selecting the top 10% of the tested genotypes from each regional selection (with 90 candidate clones each, whose ortets are plus trees selected in the pine forests for their outstanding cone yield). The genetic correlations between genetic values for cone yield and cone or seed size were always positive (r=0.17-0.47), hence no trade-off between crop quantity and quality is observed (Mutke et al., 2005a; Mutke et al., 2007). The approval of the best clones for the Spanish National Register of Basic Materials is still pending, but it will allow the marketing of their scions or grafts in the categories 'qualified' or 'tested' as defined by the Council Directive 1999/105/EC, of 22 December 1999, on the marketing of forest reproductive material (OJEC of 15 January 2000, L 11/17-40), whose Annex I includes *Pinus pinea*.

This evaluation has allowed a selective rogueing of the clone banks and the establishment of the most promising clones in a new multi-site trial that will offer information about their growth and fruiting habits at different geographic locations. The importance of this topic is evidenced by the observed strong phenotypic plasticity of stone pine growth and cone yield in dependence on soil properties and agroclimate, as well as major clone-by-environment interactions at regional scale (Mutke, 2005). Currently, there is a gap of neat knowledge about site requirement and potential of this crop, though whilst genuine stone pine forests grow mainly on sandy or rocky soils without agronomic value (that is the ultimate reason that these woodlands escaped the ploughing up since Middle Ages), grafted plantations on farmland are expected to render higher yields.

CULTURAL TREATMENTS

Variety selection is not reasonable without the development of specific cultural techniques adapted to this conifer as crop. Mutke et al. (2000a) stressed already some difficulties in comparison with traditional woody crops due to the biology and character of the species (no rooting or woody grafting, no adventitious sprouting ability that would allow crown renovation after pruning, etc.), of which the main one is the location of female flowering exclusively on the most vigorous annual shoot tips, *i.e.*

One year old shoot of *P. pinea* tip-cleft (needle graft) grafted onto *P. pinea*.

on the vertical co-dominant shoots of the crown surface. This positive association at shoot scale between vegetative vigour and reproductive investment contrasts with the classical model in fructiculture of a dichotomy between vigorous, vertical woody shoots and weaker, bended fruiting shoots so typical in most Angiosperm fruit species, putatively due to a different phytohormonal regulation of apical differentiation than in stone pine.

The stone pine crown architecture presents also a strong phenotypic plasticity depending on light environment. In open-grown stone pines, the lateral branches in full sun-light grow as much as or even more than the leader shoot, sustaining also similar branching ratios and secondary growth that stiffen them in an ascendant, co-dominant position, producing the typical polyarchic crown that is "wider than deep", spherical in youth and characteristically umbrella-shaped in older trees, bearing cones on the whole upper crown surface. On the other hand, shaded branches in the inner crown or in the closed canopy of denser stands show steep trends to reduce their successive yearly terminal shoot length as well as lateral bud number per whorl, the supported needle mass and diameter increment, and to withdraw also female flowering, tending to masculinity. In consequence, dense-grown stone pines develop a vertical, monopodial crown architecture similar to other pine species,

Two year old shoot of *P. pinea* grafted onto *P. pinea* showing flowers.

with tiers of small, dominated branches. Only vigorously growing stone pine trees with 'expanding' crowns will hence render high cone yields (Mutke et al., 2005b).

Up to the present, the few existing grafted plantations have evidenced a delayed coming-into-production, with annual mean cone yields normally less than 2 kg per tree (rendering about 0.4 kg pine nuts) during the first decade, especially in too dense planted trials where canopy cover was complete in few years and trees could not develop the expanding crown ideotype. On the contrary, in spacing of at least 6 m x 6 m (278 trees/ha), the best trees (that is the most vigorous) reached mean annual cone yields of 4-6 kg and maximum yields of 12-15 kg (2-2.5 kg pine nuts) in less than ten years after grafting. But both the initial delay and the existing yield variation between years (masting) reflect (apart from the harsh environment in Inner Spain where the studied plantations are located) the lack of even the least cultural treatment as pruning, fertilization or weed and pest control of most of these plantations, owing to the fact that they were established primarily as gene banks by forest administrations, not as agronomic trials.

PROPAGATION AND ROOTSTOCKS

The mostly used propagation technique is the tip-cleft grafting substituting in spring the terminal bud of the stock's leader shoot by a bud scion of the selected clone, using now preferentially container-raised rootstocks in greenhouse.

As in stone pine woody grafting is not feasible, scions are obtained from long shoot terminal buds (still green soft tissue), best at the moment of starting the spring flush. In order to allow a fast callus onset and early sap supply between tissues, the stock might be slightly more advanced, after bud burst though before complete shoot elongation. Phenology thus constricts the most adequate time window to about two weeks each spring, in March in the warmer southern coast area of Andalusia and not before May in the Spanish inner highlands. But it can vary in several weeks between years, depending on the accumulated day-degree sum (Mutke et al., 2003).

The grafting point is tied up with a parafilm ribbon and protected during several weeks both from water and from outdrying air by a transparent perforated plastic bag. In the moment of grafting, stock branches are cut back for avoiding competition with the scion; they are lopped completely in autumn once established the graftling's own needle biomass.

For rootstocks, no defined material is used, but any well-formed seedling of Stone or Aleppo pine serves (the latter for calcareous soils in thermo-Mediterranean climatic zones). Some trials of micro-propagation aiming clonal rootstocks for studying rootstock influence on the tree behaviour have been performed, without conclusive results in the field at the moment (Alonso et al., 2006). The relevance of vigorous shoot and crown growth for cone production will limit greatly the possibility of dwarfing stocks or high-density plantations.

ORCHARD ESTABLISHMENT: TREE SPACING

For the same reason of the phenotypic plasticity of crown development, the spacing of the trees within the orchards must be wide enough to avoid lateral shading. Besides, competition limits the vital resources of the tree, especially the water availability, the main limiting factor in Mediterranean climate. Spacing of 6 m or more are thus advisable, depending on site conditions. Stone pine prefers loose sandy soils, best with root access to groundwater (*e.g.* sand layers over river terraces), though produces well on stony sites or gravels, whereas too compact clay or silt will throttle roots (and thereby crown) development. The tree resists occasional extreme temperatures quite well (-20º - 44ºC), especially out of the main shoot-growth period in spring. The late flowering (March at the southern coasts, May to June in inland up to 1,000 m) avoids normally frost damages (Mutke et al., 2003) and only such altitudes or latitudes as with risk of heavy snowfall advise against this crop, threatening to break down the open candelabra structure of the stone pine crown. Annual rainfall should be above at least 400 mm (best more than 600 mm) if well-grown cones (about 250-350 g) are aimed, resisting the species strict summer droughts by photosynthetic close-down (Mutke et al., 2006).

The response of pinecone yield to different spacing might be highlighted by the results of two thinning experiences. The first one is an afforestation that had been grafted in the field in 1987, five years after plantation (850 trees/ha; mass-selected, non-labeled scions). After reaching complete closure of the grafted crowns few years later, in 1999 two-thirds of trees were extracted in a systematic thinning. The remaining trees responded immediately with an increment of strobilus induction and since then, the trees of the six thinned plots (8.5 m^2/ha basal area, namely the sum of stem sections above the grafting point in 2006) render all years four- to ten-fold the mean yield of the trees in the three unthinned control plots (BA 17 m^2/ha), without significant yield differences between plots before thinning. That is, the thinning nearly doubled the annual mean cone yield/ha from 180 kg to 350 kg in the last six years.

In another clonal orchard, planted in 1992 at 3 m x 3 m (1,111 trees/ha) with trees grafted the year before, we assigned in 2002 its seven replicates to a trial that contrasted and/or combined a thinning of about 50% of the 9 m^2/ha previous BA with a very light pruning (of the lower and inner weak and shaded branches only) and seasonal irrigation (weekly 50 l per tree during June and July namely during the period of main cone growth), maintaining an untreated control plot. The five thinned replicates (pruned or not) increased since then 5 to 7-fold the yield per tree of the unthinned and non-pruned control, that is three-fold per hectare (763 vs. 255 kg/ha/yr; BA 9 vs. 15 m^2/ha in 2006), even four-fold in the irrigated replicate (1,020 kg/ha/yr, BA 9 m^2/ha). Even the pruned, though unthinned replicate rendered more than twice the control yield (585 kg/ha/yr). Also the mean cone weight, variable related directly with the mean size of the extracted pine nuts (that is their market price per kg), increased about 40% after thinning (250-260 vs. 180 g), whereas no significant effect of pruning or watering on cone or seed size was found.

PRUNING

Given that in stone pine female flowering occurs mainly on the crown surface and there is no adventitious sprouting for substituting eliminated branches, no pruning is applied in the upper crown, whereas pruning of the shade crown does not influence greatly the upper shoots, except in excessively dense plantation where thinnings should be applied instead. Thus though some weak or lower branches might be eliminated, at least for facilitating cultural or harvest operations, pruning hardly will make sense financially.

Moreover, if there is no extern pollen supply by nearby adult stone pine stands, pollination will depend on the own male flowering of the orchards, thus the weak, dominated branch tips of the lower, shaded crown will be essential to support a correct cone setting. Actually, the development of vertically differentiated crowns with enough pollen output might be the main constrict for coming-into-production of new orchards placed out of established stone pine growing areas. Though this shortcoming can be solved by an artificial, electrostatic pollen supply, used for example by the French CEMAGREF in clonal *Larix* seed orchards (P. Baldet, pers. com.), this (expensive) technique for forcing small new-grafted trees into a precocious cone production would hardly make sense financially. The sound alternative is to optimise the growth conditions for archiving a fast but equilibrated crown development of the trees.

Pinus pinea female flower.

SOIL MANAGEMENT AND FERTILIZATION

The effective control of herbs and forbs by ploughing is as important as in any rainfed crop. Yield increments in cone number and size by application of fertilizers have been achieved, especially on oligotrophic sands or gravels where also meliorations by organic matter would improve soil structure and water and nutrient retention capacity (Calama *et al.*, 2007). But they must be extremely careful with animal manure that might burn the sensible conifer roots or mycorrhiza. Moreover, nutrient uptake will depend mainly on the water availability, which is the principal shortage in the stone pine's growing area. On the other hand, though irrigation would improve the cone yield, if there is access to water supply, stone pine seems hardly to be an interesting investment alternative to other, wellknown crops like irrigated annuals, grapevine or even its most direct alternative, the almond.

PEST AND DISEASE CONTROL

There are few pests or fungi that affect vigorous pines, neglecting thus opportunists on decrepit trees for example at inadequate soils or in excessive densities. The larvae of the moth *Thaumetopoea pityocampa* Schiff. can cause some defoliations, but its population is easily controlled by chemical treatments, as it is one of the most common pine-forests' pests which control is habitually aerial at greater scales. In plantations of small, grafted trees it may be eradicated even mechanically (if an organic-agriculture label is looked for) by cutting out its winter nests from the crowns. There are two insects, the weevil *Pissodes validirostris* Gyll. and the moth *Dioryctria mendacella* (Stgr.), whose cone-boring larvae can destroy or diminish the yield. The moth larvae are still inside the cones during cone harvest in winter, hence the damaged cones can be easily sorted out by their different, brownish colour, and burned, whereas the control of the (rarer and less out-spreading) weevil requires a timed chemical treatment during its short imago phase in spring or, again, if an organic-agriculture label does not allow that, by sacrificing the whole unripe harvest of the (usually a few) affected trees when detected.

HARVESTING

As well as currently in pine forests, in the future the cones might be gathered also in commercial, grafted plantations by harvesting machines, that is special vibrating jaws coupled on a jib of a farm tractor. When mecanical harvesting is envisaged, the lower tiers of the tree branches should be pruned during the first years after grafting, in order to form a robust, straight cylindrical stem of at least 2 m beneath the crown base to allow the free shaking and swinging of the vibrated crown. Besides, the clean basal stems and a bare-soil management will guarantee the orchard's defence from spreading occasional fires that are a relevant and recurrent element in Mediterranean forest and farmlands, and thus should be taken into account. Currently, strips with few, spaced lines of grafted stone pines have been tried out successfully as fire defence areas along roads or forest tracks, self-financing the bare-soil maintenance by the incomes from the cone yield (Prada et al., 1997).

CONCLUSIONS

The current knowledge about stone pine as nut crop in specific plantations might be resumed in the following points: the genetic control of seed productivity seems to be quantitative; no related major genes are still known. The association of vegetative and reproductive effort at shoot level apparently limits the potential selection of high productive dwarf varieties for modern intensive, dense fructiculture. Anyway, the managed grafted trials with selected genotypes have allowed multiplying several times the productivity of the forest land where they are located, in comparison with traditional stone pine forests. Thus their major potential might be just in the limit

Pinus pinea selection growing at the Spanish CIFOR-INIA Clonal Bank in Madrid.

between areas with and without agronomic aptitude: marginal stony or sandy Mediterranean farmlands where herbaceous crops or extensive sheep grazing are not longer profitable without subsidies and where traditional afforestations would offer only environmental benefits but no direct incomes for the land owner. But this 'agronomic limit' is currently pushed forward towards better soils by the European common agricultural policies and the ongoing rural depopulation. An agronomic programme for optimising the cultural management and for assigning the best performing clones or varieties for each agro-region is therefore undertaken currently through collaborations between the Polytechnic University of Madrid, the Spanish National Institute for Agriculture and Food Research INIA and State and Regional Forest Administrations, which will be shared in 2008 by the Institute for Agriculture, Research and Technologies (IRTA) with new plantations in Catalonia.

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IRTA Mas de Bover • Coordination Centre of the Research Network on Nuts

IRTA RESEARCH & TECHNOLOGY FOOD & AGRICULTURE

FAO CIHEAM Nut Network

Almond nuts opening their husk.

EDITORIAL

Activities 2007-2009

During 2007, 2008 and 2009 a number of activities are and will be supported by the FAO-CIHEAM Interregional Cooperative Research Network on Nuts. In March-April 2008, the XIV GREMPA Meeting on Pistachio and Almond will be held in Athens, Greece. Next June, the VII ISHS International Congress on Hazelnut will be held in Viterbo, Italy. In September 2008, the III ISHS International Symposium on Chestnut will be taking place in Beijing, China. In February 2009, the VI ISHS International Symposium on Walnut will be held in Koondrook, Victoria, Australia. Also in 2009 the V International Symposium on Pistachios and Almonds will take place in Sanliurfa, Turkey. The corresponding Proceedings will be published either in Acta Horticulturae or in Options Mediterranéennes in the case of the GREMPA Meeting.

Last year an European COST (Cooperation in the field of Scientific and Technical Resarch) proposal on bacterial diseases of stone fruits and nuts was prepared by network members and approved by European Commission. COST actions are regarded as a source of financial support to our Research Network for COST Member States. Also an AGRI GEN RES Action acronymed “SAFENUT” was submitted and approved by the European Commission for three years. A challenge for the Network members is to propose competitive R&D projects which address relevant problems of the nut sector. The 7th UE Framework Programme for R+D can be an interesting opportunity for European member countries or associates to be explored. Once carried out the projects, the generated