

## **Introducing plants for bee-keeping at any cost? – Assessment of *Phacelia tanacetifolia* as nectar source plant under xeric Mediterranean conditions**

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**Abstract.** We assessed nectar and honey potential of *Phacelia tanacetifolia*, an American plant, under Mediterranean conditions. Its flowering occurred during the major flowering season unless intensely irrigated, whereas duration and flower life span were shorter compared to continental conditions. Mediterranean climate limitations to nectar secretion were assessed on plants grown under natural conditions (xeric) vs. regular irrigation. May flowering xeric plants produced less nectar per flower than the irrigated ones, but had the same nectar potential per surface area. On the contrary, at the cost of intense irrigation, July flowering plants produced much higher nectar per flower and per surface area compared to xeric ones. In all flowering periods and sections honeybees were the most constant and numerous visitors, visiting the flowers mainly for nectar, whereas solitary bees were scarce. Based on our results, we suggest that although the plant may be a good nectar source for honeybees in some cases, we have serious reservations for a generalised use in the Mediterranean.

**Key words:** *Phacelia tanacetifolia*, Tansy/Lacy Phacelia, nectar secretion, nectar composition, honeybees, insect visitors, pollen collection, nectar/honey potential.

Although the evolution of flower – pollinator partnerships has been largely based on the energetics of floral rewards within the species natural habitats, bees may exploit extensively non-native resources, such as annual crops and orchards. This applies especially to honeybees, first because of their learning abilities and sociality, and second because these insects are worldwide managed by humans (bee-keeping, pollination-directed activities). The management may include nectar or pollen source plants introduced to regions far from their origin, aiming at supplementing honeybees with floral rewards, sometimes as a replacement to native sources. Such a plant is *Phacelia tanacetifolia* (Hydrophyllaceae), commonly known as Lacy or Tansy Phacelia (syn. Purple Tansy, Fiddleneck and Valley Velveta). Native to Californian drylands, chaparral and Central oak woodland, *P. tanacetifolia* has been naturalised throughout the western United States and frequently in Europe (Tutin 1992), whereas it has been extensively used as a nectar crop up to Australia. Usually growing in large monocultures, it flowers for a limited period, providing the bees with a sudden

abundance of food for a certain period only (Williams and Christian 1991).

Since the 60s there has been an enormous literature on *P. tanacetifolia*, focusing not only on its melliferous importance as “companion plant”, but also in agriculture and husbandry. It has been extensively used for nectar (bee-keeping, wild bee conservation in set-aside lands, as well as in pest management – mainly against aphids through hoverfly management: Williams and Christian 1991, Gathmann et al. 1994, Sengonca and Frings 1988, Bowie et al. 1995, Hickman and Wratten 1996, Williams 1997, Carreck and Williams 1997, Lovei et al. 1998, Sommaggio 1999) and for biomass (animal fodder, conservation tillage systems on erodible soils, as well as green manure or beneficial cover crop for soil fertility and reclamation of degraded soils: Williams and Christian 1991, Fielder and Peel 1992, Stiversyoung 1998, Viaene and Abawi 1998, Jackson 2000, Brofas and Varevides 2000, Brofas et al. 2000).

After its introduction into Europe in 1832, *P. tanacetifolia* has been widely recognised by beekeepers in former USSR, and northern and eastern European countries as a good nectar source for honeybees like in the USA (Williams and Christian 1991 and references therein). Although listed among the world top twenty honey plants (Crane 1975, Crane et al. 1984), its use as a honeybee plant in the Mediterranean region has been sporadic, restricted mainly to Italy and Greece (Ferrazzi and Sofi 1986, Orsi and Biondi 1987, Thrasvoulou and Tsirakoglou 1994). Despite a recent attention by some individual beekeepers, the usefulness of the plant for the Mediterranean region has not been assessed by any competent authority. Such assessment should be carried out on cost basis, both environmental (e.g. water and soil needs) and financial (e.g. seed cost), vs. benefits (e.g. quantity and quality of the honey gained, wild bee conservation), and become the fundamental tool in decision making in order to avoid any environmentally non-friendly experimentation.

The goal of this study is to explore whether *P. tanacetifolia* is an interesting melliferous

crop plant under Mediterranean conditions, in fact, whether its cultivation meets with the standards of sustainability and wise use of natural resources, especially if the peculiarities of the area are considered. In the Mediterranean, honeybee nectar needs can be satisfied by spring wild flowering marginal lands (i.e. mainly phrygana and other scrub), whereas there is nectar shortage in summer (Petanidou et al. 1995, Petanidou and Ellis 1996). Thus, *Phacelia* could be used as an “alternative” nectar source during the aestival nectar gap, in order to halt hive migration Greek beekeepers are forced to undergo (Thrasvoulou and Tsirakoglou 1994, Petanidou 2001). However, because water is very limited in summer (most precipitation in the area falls within October–April) any need for *Phacelia* irrigation would impose extreme socio-economic and ecological problems. Under such conditions of drought stress, especially in view of the probable climate change effects, the dependence of *Phacelia* on irrigation is of crucial importance and should be primarily studied.

The above signify that *P. tanacetifolia* can be considered as suitable to the Mediterranean only if its nectar yield in summer counterbalances its water demands. The specific questions addressed in this paper are whether (i) Mediterranean climate imposes limitations to growth, flowering and nectar secretion of *Phacelia*, (ii) the plant is attractive to honeybees and solitary bees, (iii) it is ecologically wise -based on irrigation needs- to introduce the plant in the Mediterranean for bees to forage (i.e. honeybees, to increase honey production; solitary bees, to enhance nature conservation), and (iv) if so, what period of the year its use is advisable.

## Material and methods

**Study species, site, and period.** *Phacelia tanacetifolia* Bentham (Hydrophyllaceae) is an annual herb 20–80 cm high and prefers sunny sites and moist soil. The flowering part of the stalk is curled, slowly unwinding as the flowers open. The bluish-violet, persistent flowers bear a 6–9 mm corolla and

5 long-exserted stamens with an equal number of anthers, and a distylous ovary.

We employed six populations of the species, cultivated in different times and sites: five at the agricultural farm of the Aristotle University of Thessaloniki at Thermi, 14 Km east of the centre of the town of Thessaloniki (dates of sowing: 10 May 1996, 12 November 1996, 18 June 1997, 9 September 1997; self-sown in June–July 1996) and one at Oraiokeastron, ca. 10 km west of the town of Thessaloniki (sowing: 10 June 1997). All were raised from imported seeds purchased in the market, with the exception of the self-sown population that derived from seeds of May 1996 sowing.

#### **Cultivation and raising conditions of *Phacelia*.**

Each sowing comprised a total area of ca. 0.1 ha. When precipitation allowed (i.e. in fall), the sown surfaces were not taken extra care, otherwise they were irrigated regularly. After germination the sown area was divided in two sections, an irrigated and a non-irrigated one, hereafter called *irrigated* and *xeric*. The irrigated section continued to be regularly irrigated ca. every 3 days even during the sampling period, whereas the xeric one not. However, under the extreme summer drought (July–August), even the xeric populations had to be irrigated when in flower in order to keep alive.

The effect of sowing time on the differential growth and flowering of *Phacelia* was estimated in all six populations. Detailed nectar measurements, pollination experiments and observations were carried out on two population cases (May and July 1997), in both the irrigated and xeric sections. Pollination management was made by placing 4–5 hives at a distance of up to 50 m from the sections, so that honeybees had equal access probabilities to both. Fieldwork observations, nectar collection and experiments were systematically carried out between 14–28 May and 26 July to 6 August 1997 for the May and July populations, respectively.

**Flowering and floral characteristics.** A population was considered to be in flower when the flowering plant density exceeded 1 per m<sup>2</sup>. In order to estimate flower life span, flowers from several individuals were cleared away at different times of the day, and followed thereafter every half hour until the initiation of flower anthesis, then every 1 h until withering ( $n_{\text{May}} = 46$ ,  $n_{\text{July}} = 31$ ).

**Flower and fruit potential.** In all populations and sections flower potential was estimated on the basis of the plant density (measured with the aid of

a square frame 50 × 50 cm), the number of ramets or inflorescences per plant, and the total number of flowers per ramet/inflorescence.

The effect of drought vs. irrigation was investigated on the differential biomass performance and seed production of both xeric and irrigated sections on the population flowering in July. As to biomass, all plants occurring in 4 different frame plots (each of 0.25 m<sup>2</sup>, selected at random) were collected at the high peak of flowering in the irrigated and xeric section separately (28 July), cleaned from earth, dried at 60 °C until constant weight, and weighed some days later. Using the same protocol, all fruited plants of 4 × 0.25 m<sup>2</sup> plots were collected few weeks later (18 August), and their fruits/plant and seeds/fruit counted at random.

**Nectar – Field measurements.** Nectar volume (in µl), concentration (as % w/w) and sugar content (w) were measured following the methods described by Petanidou and Smets (1995). The measurements were carried out using the destructive method on flowers 2 to 3-h old ( $n = 13–31$ ) with 0.5-µl to 1-µl microcapillaries (Drummond) and a pocket refractometer (Bellingham & Stanley, Tunbridge Wells).

**Nectar collection and analyses.** Nectar for laboratory analyses (per flower content of individual sugars: sucrose, glucose, and fructose) was collected in the wild on Whatman n° 1 paper wicks. Description of the method of collection (field), retrieval (laboratory) and analysis (HPLC) are available in Petanidou and Smets (1995), Petanidou et al. (1996, 2000) and Petanidou (1998).

**Pollinators – Behaviour.** Visitation rate was studied in plots of 2 × 1 m each (May) and of 1 × 1 m (July), in all irrigated and xeric sections. The compared xeric and irrigated plots had similar inflorescence densities.

Pollinator visitation was measured at least every 2 h, by one person spending 15 min at each plot and counting the number of individual insects paying visits to the flowers inside the plot. Besides honeybees (responsible for more than 95% of the total number of visits to the flowers of *Phacelia*), attention was also given to visitor groups such as hoverflies and beetles, both relatively common, sweat bees and butterflies, both relatively frequent, whereas others, such as Anthophoridae bees and Muscidae flies were extremely rare.

In a second set of observations carried out in parallel and following the same time protocol, we

noted the floral reward type collected by honeybees. Walking along a 15 m transect for 15 min, the observer followed honeybees, each for 15–50 consecutive visits to *Phacelia* flowers, in order to assign them as nectar-gatherers, pollen-collectors or exhibiting a mixed diet preference. Number of honeybees followed per day period and section varied from 6 to 50. In cases that the total number of honeybees was too small, we augmented observation time until a sufficient number of bees was reached. Observations were carried out throughout five entire days in the first population (15 to 20 May) and four in the second one (26 July to 4 August).

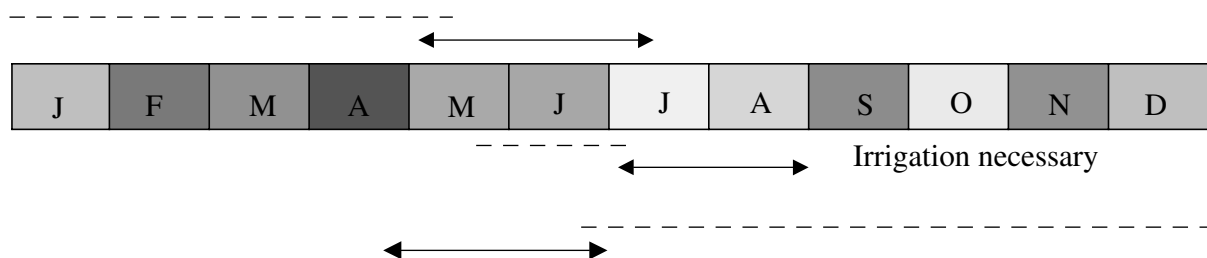
**Pollen analysis.** In order to detect the importance of *Phacelia* pollen for honeybees, we studied the profile of the pollen collected by the bees during 7 consecutive days in both periods and study sections (22–28 May, 30 July–4 August). In all cases, the investigation was preceded by setting a 2-day bee training project to the pollen traps. The latter were installed in four hives located ca. 30–50 m from *Phacelia* populations, one in the entrance of each hive. They were left open (free entrance traps) for one day so the bees get accustomed, and closed during the following ones. Pollen was collected from the third evening on. All pollen lumps collected per day and trap ( $n=10-60$ , 0.5–12 g each) were separated into colour groups and weighed. Each pollen group was identified microscopically ( $n=5-6$  lumps/group) using pollen reference material collected on the spot. Pollen collected from traps or flowers was transferred to a glass slide and washed with ether. The grains were stained with aqueous basic fuchsin 1%, dried at 40 °C and fixed with Canada balsam to be examined later. The pollen profile was calculated on the basis of the identification and weight of each pollen group separately.

**Data analysis.** In all statistical analyses we employed Kruskal–Wallis  $H$  anova and Mann–Whitney  $U$  non-parametric tests. Visitation rates of honeybees between xeric and irrigated sections at different times of a day were compared by employing the Wilcoxon Matched Pairs  $T$  test. In *a posteriori* comparisons the ultraconservative Bonferroni correction was applied (Petanidou and Smets 1995, Petanidou et al. 1995).

## Results

**Flowering.** The blooming response of *P. tanacetifolia* in respect to sowing time is summarised in Fig. 1. Flowering took place a couple (same year) or several months after sowing (next year's flowering period). In general flowering occurred late spring to early summer (late April to early July), unless the plants were regularly and intensely irrigated; then a flowering could also take place in high summer, until the end of August, which, though, was rather irregular. There was no autumnal flowering response in later sowings under any irrigation condition, and the plants remained vegetative during long winter periods. Flowering period varied between 5–7 weeks, depending on the period of the year and the specific conditions. The flowering duration of xeric populations was somewhat shorter in time, between 25–45 days.

**Flower, fruit and seed potential.** The flowers of *P. tanacetifolia* are homogamous, becoming receptive as soon as they open. Their life span was very short, lasting between 2.5 and 4 h, up to a maximum of 5 h. Because anthesis was not restricted in time within a day, open flowers were found all day long.



**Fig. 1.** Blooming response (continuous line) of *Phacelia tanacetifolia* in Thessaloniki metropolitan area, in relation to sowing time (dashed line). In the middle case flowering is possible only under compulsory irrigation

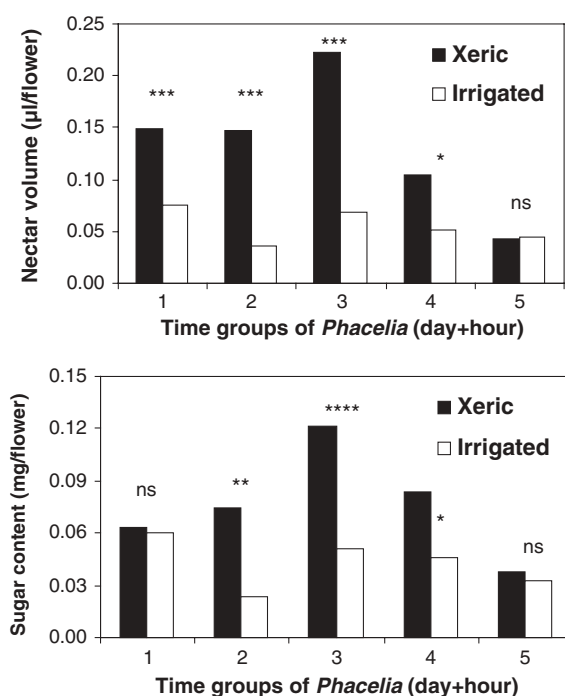
**Table 1.** Comparative numbers on growth and reproductive success illustrating the performance of *Phacelia* in the xeric and irrigated sections of the populations flowering in May (Thermi) and July (Oraiokastron). N is the sample number and SE the standard error. ns:  $P > 0.05$ , \*\*\*\*:  $0.001 < P < 0.0000$ 

	Xeric section			Irrigated section			P
	Mean value	SE	N	Mean value	SE	N	
Flowering in May							
# flowers per stem	23.0	2.48	32	33.0	4.03	26	ns
# flowering stems per m <sup>2</sup>	70.0	4.75	22	71.5	5.22	25	ns
# seeds/fruit	2.61	0.075	165	2.84	0.094	203	ns
Flowering in July							
# plants per m <sup>2</sup>	89.1			445.3			
plant net weight (g/m <sup>2</sup> )	164.8			427.4			
weight of flowering plants (g)	2.2			1.2			
# flowers/plant	229.6			162.2			
# fruits/plant	183.1	40.99	10	131.3	18.16	12	ns
# seeds/fruit	2.23	0.063	325	1.64	0.058	365	****

There was no difference either as to plant density or to seeds recovered per fruit between the xeric and irrigated section in May (Table 1). However, the numbers in July were quite different: much higher plant density and biomass in the irrigated section,

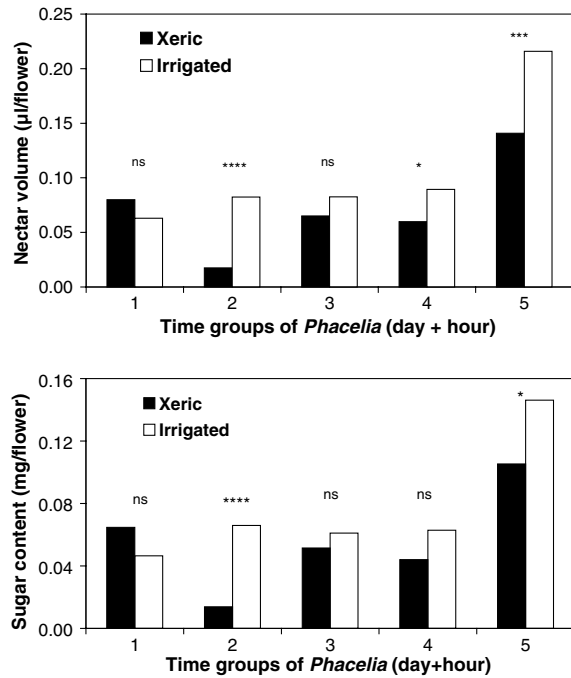
resulting to a lower per plant biomass. Interestingly, this irrigated section bore lower number of seeds per fruit compared to the xeric section (M-W  $U_{[325, 365]} = 41803.500$ ,  $P = 0.0000$ ), but the same number of fruits per plant ( $P = 0.2914$ ).

**Nectar – Honey potential.** Nectar secretion levels of the populations studied are summarised in Figs. 2 and 3 for May and July flowering, respectively. The figures include also the statistical differences between comparable time groups of *Phacelia* nectar secretion in the xeric and irrigated sections. The first conclusion based on these data is that in both periods and sections, nectar secretion of *Phacelia* flowers is time- and day-dependent. As to the differences between the two sections, nectar



**Fig. 2.** Volume and sugar content of the nectar produced by *Phacelia* flowers in May 1997. The flowers belonged to comparable time groups (same day and time) in both the xeric and the irrigated sections of the population. Statistical differences between the xeric and irrigated sections are noted above the bars: \*:  $P < 0.05$ , \*\*:  $0.05 < P < 0.01$ , \*\*\*:  $0.01 < P < 0.001$ , \*\*\*\*:  $0.001 < P < 0.000$ ; ns:  $P > 0.05$ )

secretion per flower is higher in xeric vs. irrigated flowers in May, but the situation is reverse in July, when nectar secretion per flower tends to be higher in irrigated vs. xeric flowers.



**Fig. 3.** Volume and sugar content of the nectar produced by *Phacelia* flowers given in comparable time groups of the xeric and the irrigated sections of the population flowering in July 1997. Statistical differences between the xeric and irrigated sections are noted above the bars: \*:  $P < 0.05$ , \*\*\*:  $0.01 < P < 0.001$ , \*\*\*\*:  $0.01 < P < 0.000$ , ns:  $P > 0.05$ )

Table 2 gives the results from sugar analysis (HPLC) of nectar collected in all sections studied. In all cases the nectar is sucrose-dominant. It is very interesting, though, that irrigated flowers in July tend to be more sucrose-dominant compared to the xeric ones of the same period, which is not the case in May flowers.

Table 3 gives an estimate of the honey production in each section and population based on the nectar secretion (cf. Figs. 2–3) and flower potential measurements of the study (cf. Table 1), and on the assumption that all sugar nectars are transformed into honey at a rate 85:100 (cf. Petanidou and Smets 1995). Based on these estimations we conclude that the honey production in May is expected to be more or less the same in both irrigated and xeric sections. Not surprisingly, the differences between the two sections were extreme during the July flowering, when nectar and honey potential of the xeric section were dramatically low compared to the irrigated section. It should be noted that the extremely low nectar potential of May vs. July flowers is to be assigned to the site difference.

**Flower visitors.** In all cases the main and constant visitors to *P. tanacetifolia* flowers were honeybees from the hives placed in the study sites. In addition, the flowers were visited by other insect species for nectar or/and pollen. In May such visitors were hoverflies [*Sphaerophoria scripta* Linnaeus, *Eupeodes corollae* Fabricius, *E. luniger* (Meigen), *Scaeva pyrastris* Linnaeus], butterflies [*Maniola jurtina*

**Table 2.** Results from sugar analysis (HPLC) of *Phacelia* nectar (May and July populations). We give the per flower quantities of glucose, fructose and sucrose found in the xeric and irrigated sections. The results are averages  $\pm$  SE over 4 flowers analysed. The sucrose/hexose ratio was calculated on weight basis

Date	Treatment	Sugars			
		Glucose	Fructose (nmoles per flower)	Sucrose	S/(G + F)
20/5	Non-watered	65.2 $\pm$ 15.05	48.8 $\pm$ 12.12	164.5 $\pm$ 52.71	2.7
20/5	Watered	48.6 $\pm$ 5.78	35.0 $\pm$ 5.32	118.4 $\pm$ 14.46	2.7
28/7	Non-watered	66.0 $\pm$ 14.42	54.8 $\pm$ 12.28	115.2 $\pm$ 9.80	1.8
28/7	Watered	63.5 $\pm$ 28.19	46.7 $\pm$ 22.03	164.2 $\pm$ 90.28	2.8

**Table 3.** Estimated sugar and honey production for the populations studied. Estimates are based on nectar secretion and flower potential measurements (cf. Table 1, Figs. 2–3). Honey equivalent has been calculated on the assumption that all sugar nectars are transformed into honey at a rate 85:100

	Field measurements		Average estimations	
	Nectar yield (mg sugars/flower)	Flower potential (# flowers/m <sup>2</sup> )	Nectar potential (kg sugars/ha)	Honey potential (kg/ha)
May flowering (Thermi site)				
Xeric	0.070	1,610	1.127	1.326
Irrigated	0.043	2,360	1.015	1.194
July flowering (Oraiokastron site)				
Xeric	0.058	16,296	9.452	11.120
Irrigated	0.077	58,429	44.990	52.929

Linnaeus (Satyridae) and *Pieris rapae* Linnaeus (Pieridae)] and small-sized bees (*Lasioglossum* sp., *L. tectus* Radoskowsky, *Halictus cochlearitarsis* Dours). Large sized-bees [e.g. *Tetralonia alternans* (Brullé), *Xylocopa iris* (Christ), and *Eucera* sp.] were relatively rare. Beetles such as *Oxythyrea cinctella* Schaum, *Valgus hemipterus* (Linnaeus) and *Tropinota hirta* Poda (all Scarabaeidae), *Leptura livida* Fabricius (Cerambycidae), *Trichodes sexpustulatus* Chevrolat (Cleridae), *Drilus* sp. (Drilidae) were often found on the flowers, exhibiting, though, few visits.

In July, apart from honeybees *Phacelia* flowers were also visited by sweat bees for pollen (pollen thieves), commonly by *Halictus cephalicus* Morawitz, *H. cf. sajoii* Bluethgen, and *Pseudapis diversipes* (Latreille). Other bee visitors were *Ceratina cyanea* (Linnaeus), *Andrena cf. limata* Smith, and *Hylaeus cf. meridionalis* Foerster. All bees were females. Among hoverflies only *Eristalis arbustorum* Linnaeus was found to visit the flowers, gathering mainly pollen and occasionally nectar, whereas beetles (*Oxythyrea cinctella* Schaum) were very rare.

The insect visitation rate to *Phacelia* flowers at different periods and sections is given in Figs. 4, 5 as average over several days. The daily patterns of visitation in May are similar in the two sections, but they appear to differ in July, when xeric is behind the irrigated section

mainly in the afternoon hours (Fig. 5). Based on the average visitation rate exhibited by honeybees, there were no differences between the xeric and irrigated sections in May (15 May:  $T_{[5]} = 0.000$ ,  $P = 0.0679$ ; 16 May:  $T_{[7]} = 4.000$ ,  $P = 0.0910$ ; 20 May:  $T_{[7]} = 6.500$ ,  $P = 0.2049$ ; Wilcoxon Matched Pairs test). Similarly, honeybees did not show preference for any of the sections on July 26 ( $T_{[3]} = 0.000$ ,  $P = 0.1088$ ) and July 28 ( $T_{[5]} = 4.000$ ,  $P = 0.3452$ ), but they did show marginal preference for the irrigated vs. xeric section on July 29 ( $T_{[5]} = 0.000$ ,  $P = 0.0431$ ).

Honeybees visited the flowers for nectar and pollen, specialising to either of them (nectar gatherers – pollen collectors) or having a mixed collecting preference. All three types were active throughout the day in all periods and sections followed (Fig. 6). This may be attributed to the fact that, although continuously produced by newly opening flowers throughout the day, nectar was very fast sucked away, as indicated by the extremely low standing crop. Nectar standing crop in May was 0.0052 (10 h), 0 (14.30 h), 0  $\mu$ l/flower (18 h) in the xeric, and 0.0016, 0, 0  $\mu$ l/flower, respectively, in the irrigated section.

As a whole, honeybees showed a stronger tendency to visit flowers for nectar vs. pollen only on May 20 in the xeric section ( $T_{[6]} = 0.000$ ,  $P = 0.0431$ ), whereas no other difference was observed between days and sections during this month ( $1.000 \leq T \leq 10.000$ ,  $0.0796 \leq P \leq 0.9165$ ).

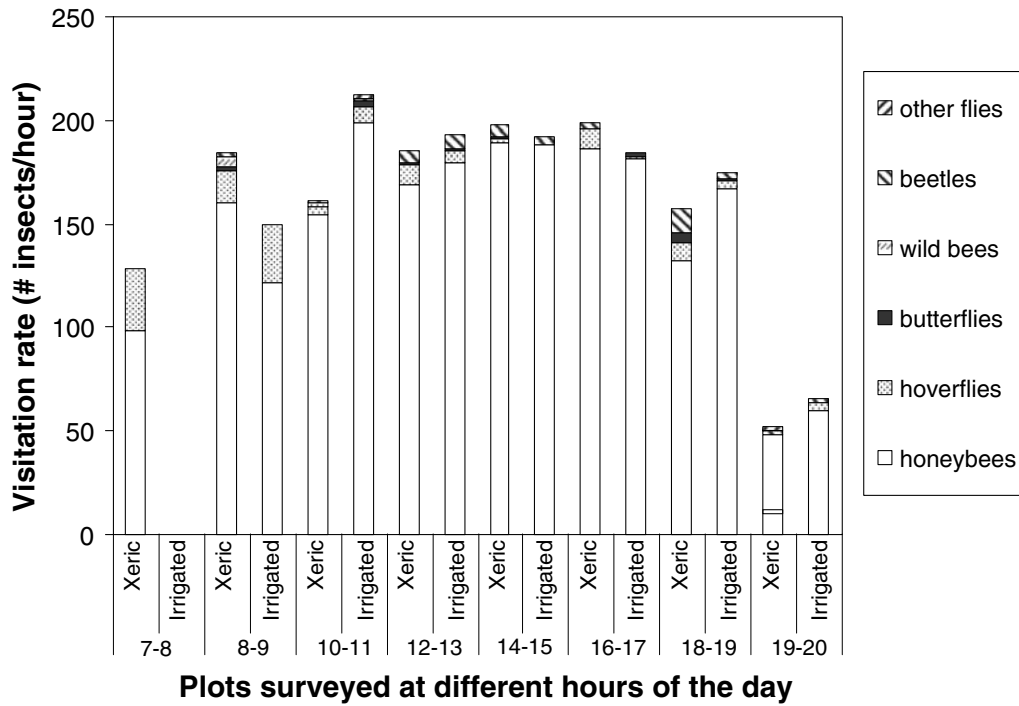


Fig. 4. Temporal variation of the number of insects visiting the 2 × 1 m plots in the xeric and irrigated sections of the *Phacelia* population flowering in May. The data are averages over five observation days (15–17, 19–20 May 1997). Differences for the period 7–8 h are due to shade dominance over the irrigated plot at that time

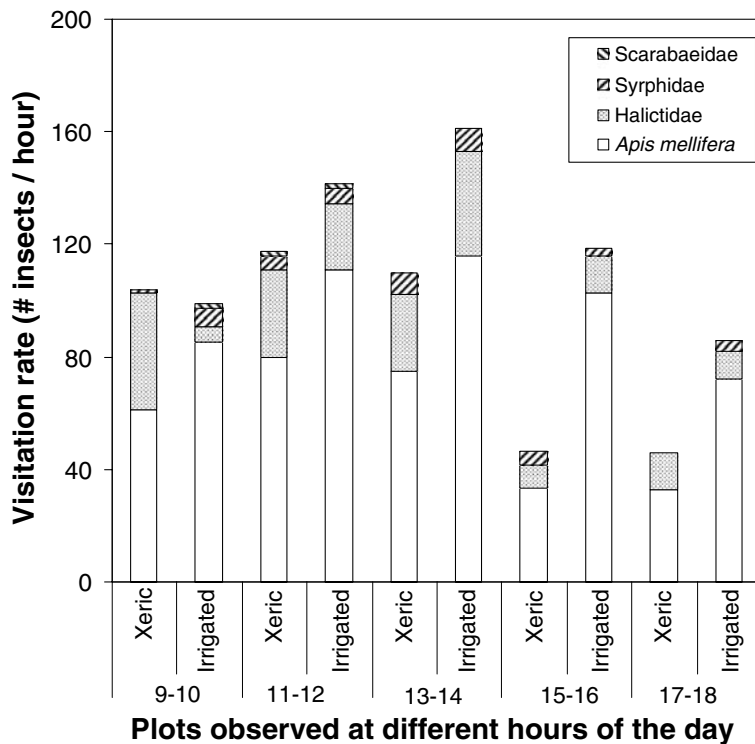


Fig. 5. Temporal variation of the number of insects visiting the 1 × 1 m plots in the irrigated and xeric sections of *Phacelia* in July. The data are averages over four observation days



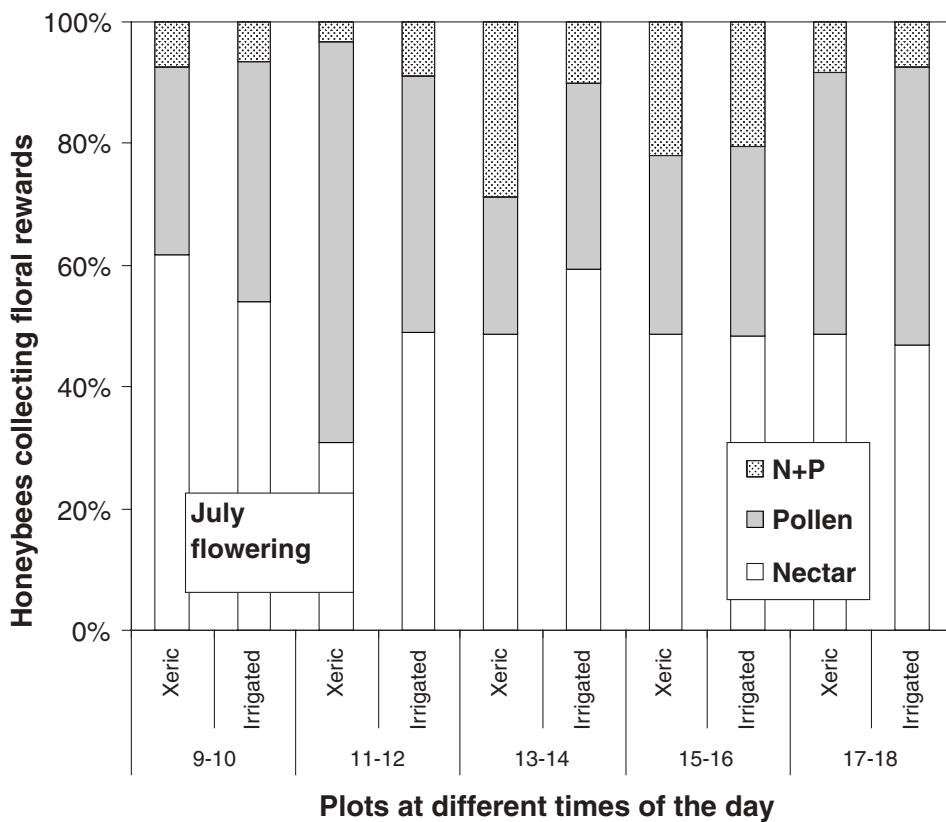
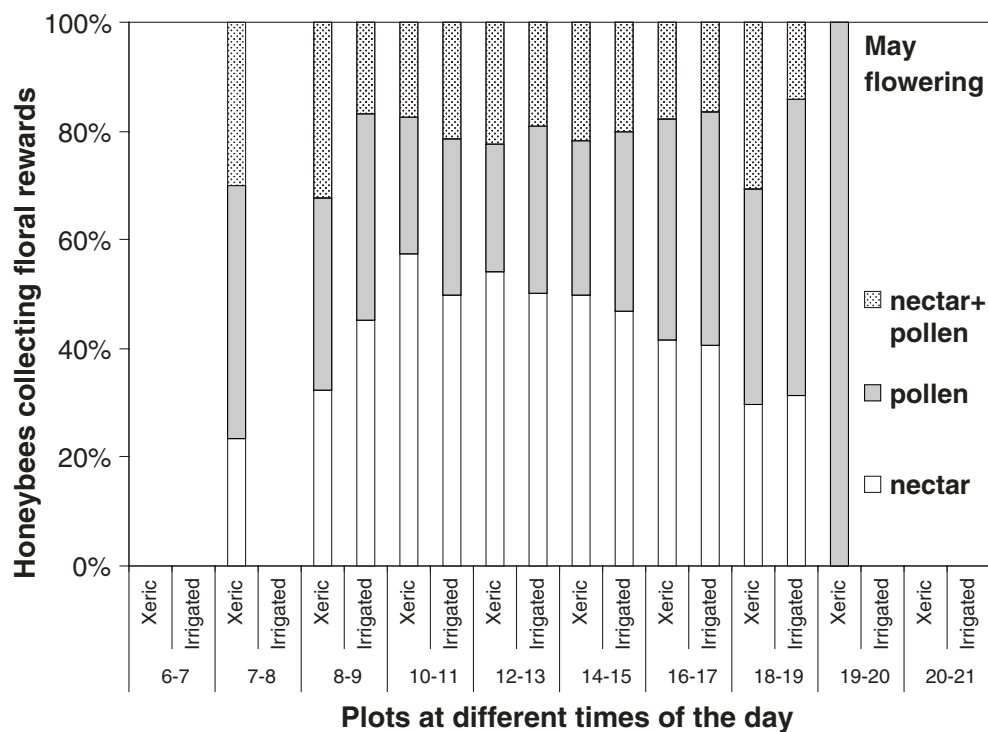
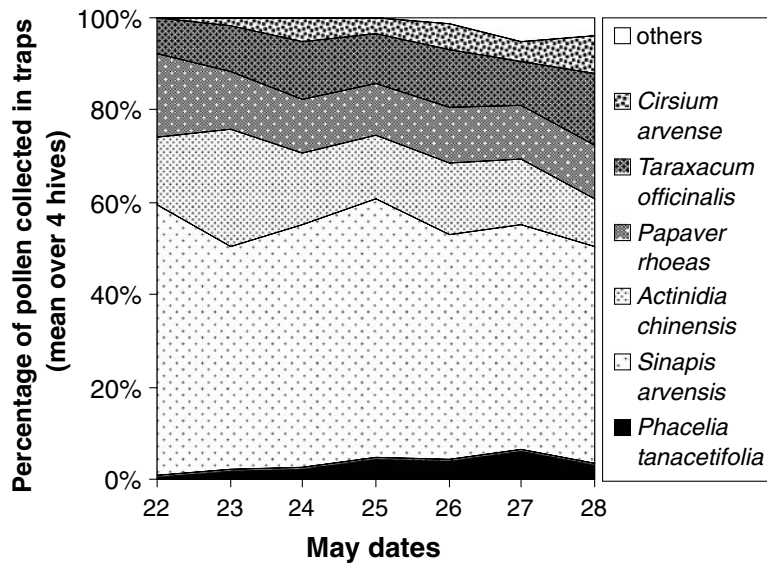
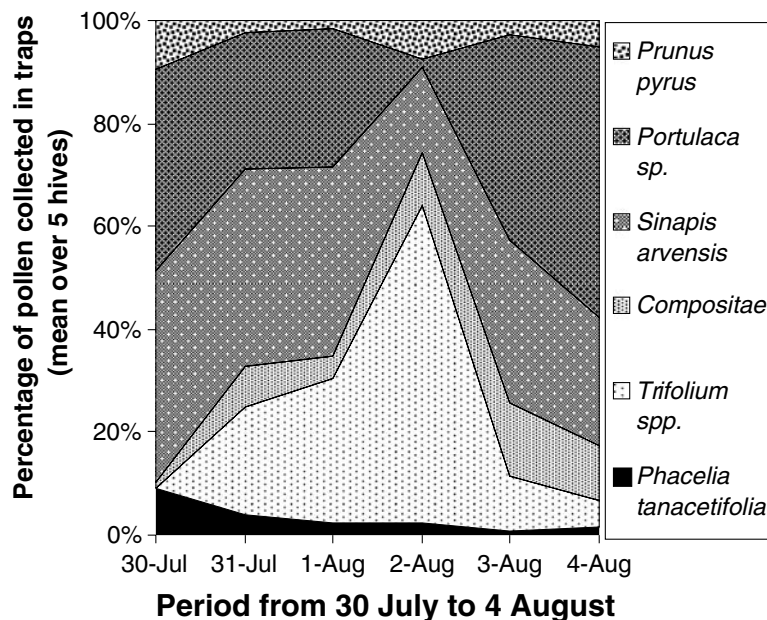


Fig. 6. Percentage of honeybee individuals gathering nectar, pollen or having a mixed preference on floral rewards of *Phacelia* at different day times, sections and flowering periods



**Fig. 7.** Profile of the pollen collected by honeybees from hives placed near to the *Phacelia* population at Thermi in May 1997. Numbers are percentages over the total weight of pollen collected per day in the hives



**Fig. 8.** Profile of the pollen collected on a daily basis by honeybees from hives placed near to the *Phacelia* population at Oraiokastron (July flowering). Numbers are percentages over the total weight of pollen collected per day in the hives

Similarly, honeybees did not show any preference for nectar vs. pollen on any of the days in July ( $1.500 \leq T \leq 3.000$ ,  $0.1057 \leq P \leq 0.2249$ ). Between May and July, or between xeric and irrigated section there were no major differences in honeybee diet preference (Fig. 6).

The profile of pollen collected by honeybees during the high peak of *Phacelia* flowering is shown in Figs. 7 and 8. In both periods,

*Phacelia* makes only a small fraction of the pollen collected by honeybees, despite of the fact that the hives were located very near to this specific pollen origin.

## Discussion

**Flowering of *Phacelia* under Mediterranean conditions.** Although our field data show that

flowering of *P. tanacetifolia* is strongly season-dependent (Fig. 1), the species may extend its flowering outside the major blooming period. Under Mediterranean conditions, its flowering is restricted between late April – early July, whereas it can exhibit summer flowering only under intense irrigation. The rather irregular summer flowering, however, as also documented by earlier studies in the same site underlines the natural preponderance of the species to flower in spring (Thrasylvoulou and Tsirakoglou 1994). However, outside Mediterranean the species can equally flower from July to December showing high flower densities as shown at Thessaloniki in spring (Williams and Christian 1991).

Further to the difference in blooming time, flowering of *P. tanacetifolia* is much shorter in the Mediterranean compared to continental climates. According to Williams and Christian (1991) the flowering of three populations from July to December lasted 50, 54, and 67 days (average 8 weeks), whereas in Thessaloniki the comparable periods were much shorter, varying from 25 to 50 days. Another time difference is that of the flower life span, which is, again, shorter around Thessaloniki (2.5–4 h) compared to continental climates (exceeding 7 h, according to Williams 1997).

All the above data show that agronomically *P. tanacetifolia* faces certain growing and flowering constraints in the Mediterranean, at least compared to continental UK climate. The difficulties are caused either by summer drought that may affect its germination, growing, and flowering, or by the heavy autumnal – winter rains that may disturb the establishment of germinating plants. Yet, another type of disturbance is caused by the intense irrigation that on the one hand is compulsory for summer flowering (July–August), but on the other hand it causes extreme problems of nutrient competition by high weeds.

**Does Mediterranean climate impose limitations to nectar secretion of *P. tanacetifolia*?** In all cases examined in this study, nectar secretion of *P. tanacetifolia* flowers appears to be

time-dependent and varies largely between days, probably due to weather conditions. Our experimental data show that weather or climate limitations to nectar secretion of *P. tanacetifolia* are set mainly during the July flowering, not in May. Throughout May flowering, nectar secretion per flower was higher in the xeric vs. the irrigated section (Fig. 2), but the overall secretion per surface area remained the same (Table 3). This was probably due to the differential nutrient allocation of the irrigated plants (allocation to vegetative parts) vs. the xeric ones (allocation to flowers/seeds). On the contrary, the limitation imposed by the Mediterranean climate on the July flowering *P. tanacetifolia* was extremely high, expressed through a much higher nectar secretion per irrigated flower (Fig. 3, Table 2) and a superior flower potential per surface area (Table 3). All the above show that non-irrigated *P. tanacetifolia* can perform well only if it flowers until May, because the plant is not adapted for summer flowering under the harsh Mediterranean conditions, such as *Thymus capitatus* (Petanidou and Smets 1996).

The above Mediterranean limitations are also supported by the sugar content results (Table 2). Sugar content of irrigated July flowers is qualitatively and quantitatively similar to xeric May flowers, probably as a consequence of equally high photosynthetic rates. It is interesting, though, that the only hexose-reduced flowers are those undergone a harsh drought limitation (xeric flowers in July), whereas all the others, including the irrigated ones in July are sucrose-dominant. This may imply that high hexose nectars are induced by drought limitation, which could be related to the low yielding Mediterranean summer flowers pollinated by short-tongued bees (Baker and Baker 1983, Shmida and Dukas 1990, Petanidou and Ellis 1996). This hypothesis needs further investigation.

**Importance of *P. tanacetifolia* to wild bees and other anthophilous insects.** As denoted by the observed visitation rates, *P. tanacetifolia* is a very interesting plant for honeybees under all periods, irrigation regimes and areas surveyed

in Thessaloniki metropolitan area. However, judging from the species and number of visiting bees, the plant does not appear to have the same importance to bees other than honeybees. For instance, it is not attractive to bumblebees as it is in continental climates (Williams and Christian 1991), nor plays the role of “cornucopian species” as some phrygic plants do by hosting a great deal of flower visiting insects and by functioning as “bridges” for the anthophilous fauna in a Mediterranean community (Petanidou 1991, Petanidou and Ellis 1996). It is worth mentioning that wild bees are represented by few species in our data (6 in each flowering period) with a notable activity only during July.

Honeybees did not show any preference for either xeric or irrigated sections in May, whereas they showed some preference to irrigated vs. xeric section in July, especially in the afternoon hours (Fig. 5). In all sections and populations the honeybees visited the flowers for nectar and pollen, although in none of the cases pollen of *Phacelia* appeared to be a major reward for the bees, as it was nectar. All the above limit, again, the role *Phacelia* could play as an eventual food source for bees in the system.

**Assessing the value of *P. tanacetifolia* as a nectar source plant under Mediterranean conditions.** Our empirical data let us conclude that introduction and cultivation of *P. tanacetifolia* under Mediterranean conditions is ecologically compatible only as a May flowering crop, when the crop does not need irrigation and the probability for pollinator or nutrient limitation is low (Table 1). During this period *Phacelia* could be used as a rotation crop in fallow lands. However, this would certainly have a negative impact on the equilibrium of the native flora and vegetation. Besides, it would have a tremendous impact on the anthophilous fauna, by attracting extremely high numbers of honeybees and discouraging small- and medium-sized solitary bees (Fig. 4). This unfair competition of honeybees to solitary bees has been also documented and discussed by Williams and Christian (1991)

and shows that at least in the Mediterranean the use of *Phacelia* is not well-suited to nature, especially as to bee conservation practices.

During July flowering, the applied irrigation, by allowing nutrient allocation to continuous vegetative development, results in competition for nutrients in the irrigated section, demonstrated as lighter plants and fewer seeds per fruit in the irrigated section (Table 1). Despite this competition, the nectar secretion is very high, allowing an alluring compensation to flower visitors, at the cost of precious water. As to the xeric section, although it appears interesting as a compromise, it should be noted that sporadic irrigation was necessary even there, a fact that underlines the harshness of the climate to be confronted.

The assessment on the use of *P. tanacetifolia* in the Mediterranean is not easy. Advantages are the strong honeybee preference, and the high nectar yield in all periods and sections, which exceeded by far that of the phrygana, the wild vegetation of the area (0.455 kg/ha according to Petanidou and Smets 1995). Disadvantages are the low attractiveness to solitary bees and honeybee competitiveness, the mass and relatively short flowering period, the need for successive sowings and seed costs, the additional environmental cost for irrigation outside the main flowering period. Besides, there is always the invader risk, due to the lack of information on the long-term impacts that *Phacelia* may have on the native flora. Further, considering that (i) there is no evaluation on the quality of *Phacelia* honey, and (ii) Mediterranean region produces a big variety of very high quality honey, we find it embarrassing to replace, even to a limited extent, the traditional Mediterranean honey from natural shrublands and marginal lands, by an easy to manage introduced crop.

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