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Taxus Populations and Clippings Yields at Commercial Nurseries

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Summary. A natural product known as taxol has been approved by the FDA for treatment of ovarian and breast cancers. In addition, preliminary clinical studies have shown encouraging results when using taxol

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to treat melanomas, lung, head, and neck cancers. Ornamental yews have been identified as a potential renewable source of taxol and related taxanes. Commercial nurseries were surveyed during Summer and Fall 1991 as a basis for estimating populations of *Taxus* cultivars currently growing in the United States. Clippings of selected cultivars were sampled from nursery fields in Ohio and Michigan to estimate expected clippings yields as a function of cultivar and cultivar age. More than 30 million *Taxus* plants were reported to be grown by the 19 major nurseries that responded to the survey. About 88% of all *Taxus* plants reported in the survey were grown in the three-state area of Ohio, Michigan, and Pennsylvania. *Taxus* × *media* 'Densiformis', 'Hicksii', and 'Brownii' were found to be grown by nearly all nurseries in the survey; more than half grew *T. × media* 'Wardii' and *T. cuspidata* 'Capitata', while other well-known cultivars seem to have been specialties of one or two nurseries. Annual clippings yields on a dry-weight basis (db) ranged from ≈20 g/plant to 140 g/plant. Expected yields were found to be very dependent upon plant age and cultivar. *Taxus* × *media* 'Hicksii' appeared to be the most ideal ornamental yew that could provide a renewable source of taxol because of immediate availability and potential for mechanical harvesting of upright clippings. An estimated 3000 to 4000 ovarian cancer patients could be treated annually with the taxol currently available for extraction from *T. × media* 'Hicksii' clippings.

The development of the chemotherapeutic cancer drug, taxol, was designated an "emergency priority" by the National Cancer Institute (Broder, 1992). While bark from the Pacific yew (*Taxus brevifolia* Nutt.)

is currently the only FDA-approved source of taxol, approval for the use of alternative plant parts or plants as sources of the common precursor, 10-deacetylbaccatin III, and/or taxol is probable (Cragg et al., 1993).

A popular ornamental hybrid yew, *T. × media* 'Hicksii' Rehd., recently has been evaluated extensively as a source of taxol and taxanes (personal communication). New-growth shoots, which typically are pruned on an annual basis as a part of standard cultural practices in nurseries, and roots and needles from cull plants, are the preferred sources of taxol and other taxanes from ornamental yews. *Taxus* × *media* 'Hicksii' has been targeted for priority evaluation for the following reasons:

- Taxol and taxane yields are comparable to or greater than other *Taxus* cultivars (ElSohly et al., 1992; Mattina and Paiva, 1992; Witherup et al., 1990).
- Upright shoots produce clippings that facilitate mechanical harvesting.
- *Taxus* × *media* 'Hicksii' is among the more abundantly grown ornamental yews in the United States (see survey results below).
- *Taxus* × *media* 'Hicksii' is grown as a nursery field crop, and therefore offers an immediate, renewable resource for annually pruned cuttings that are otherwise discarded.
- Clippings from ornamental yews may be less costly to harvest and process than bark from wild plants such as the Pacific yew tree (*Taxus brevifolia*).

While *T. × media* 'Hicksii' appears to be a promising cultivar, many other *Taxus* cultivars are being collected and evaluated (Croom et al., 1992a; ElSohly et al., 1992; Mattina and Paiva, 1992). More than 100 cultivars are included in the Chadwick Living Herbarium of *Taxus* at the Ohio Agricultural Research and Development Center.

An example of concentrations of taxol and 10-deacetylbaccatin III are shown in Table 1 for needles from six *Taxus* cultivars. While the highest concentration of taxol came from *T. × media* 'Hicksii', the highest concentration of the precursor came from *T. baccata* 'Repandens' Parsons and Sons. In more-recent research, Wheeler et al. (1992) reported that epigenetic factors (timing of harvest, plant tissue type, etc.) and environmental factors (soil type, climate, fertility, etc.) may be confounding current efforts to es-

Table 1. Concentrations of taxol and the common taxol precursor, 10-deacetylbaccatin III, from needles of six *Taxus* cultivars (Witherup et al., 1990).

Taxus cultivar	Concentration (dry-wt basis)	
	Taxol (mg·kg ⁻¹)	10-deacetylbaccatin III (mg·kg ⁻¹)
<i>T. baccata</i>		
‘Repandens’	30	200
<i>T. brevifolia</i>	60	100
<i>T. canadensis</i>	90	20
<i>T. cuspidata</i>		
‘Capitata’	80	20
<i>T. × media</i>		
‘Densifformis’	20	70
<i>T. × media</i>		
‘Hicksii’	100	90

establish expected taxol and taxane yields for selected *Taxus* cultivars. They observed that higher taxol yields were obtained from *T. brevifolia* that grew in cool, moist, shady environments than from trees that grew in warm, dry, sunny climates. Protocols pertaining to harvesting, handling, drying, processing, and laboratory analyses need to be defined. Each part of the system may have a significant effect on expected taxol and/or taxane yields (Croom et al., 1992b; Hansen et al., 1992, 1993; Ketchum and Gibson, 1993; Richheimer et al., 1992).

Along with identification of ideal cultivars and protocols for taxol and/or taxane production on a renewable basis, an estimate of populations or acreage of each *Taxus* cultivar currently grown in nurseries in the United States and other countries needs to be established. Other than for purposes

of propagation, *Taxus* clippings have not been harvested or stored routinely; therefore, no estimates of potential yields for clippings and/or needles are available.

Objectives

The objectives of this research were to: 1) survey nursery growers and account for the diversity and abundance of *Taxus* cultivars currently being propagated and cultivated for the ornamental market, and 2) measure clippings yields as a function of *Taxus* cultivar and cultivar age.

Procedures

Survey forms designed to determine types, ages, and quantities of ornamental *Taxus* grown by nurseries in the United States were distributed to 68 nurseries in May 1991. The nurseries selected for the survey included all nurseries in the United States that were believed to be growing significant collections of one or more *Taxus* cultivars. The survey forms requested an accounting of propagation, field-grown, and container-grown *Taxus* plants. Results were returned from 18 nurseries during Summer and Fall 1991. One additional nursery returned a survey 15 Mar. 1992. The data collected for field-grown plants for 17 of the 19 nurseries that responded to the survey were selected for the summaries and analyses included in this report. The two that were excluded reported that they did not grow *Taxus*.

During Apr. and May 1992, the quantity of clippings to be expected

during annual pruning of various ornamental *Taxus* plants at various ages was measured (see Table 2). Fifty plants were selected at random from each field (selection was based on random number tables) independent of field size or number of plants in the field. In fields with plant populations >3000, four to six rows were selected at random, followed by random selection of 50 plants to be pruned from the identified rows. The degree of pruning and desired plant shape was determined according to the preferences of the grower. Soil conditions permitted retrieval of nearly all plant material pruned from the plant. Pruning was done consistently with one person skilled with the use of hand pruning shears. All clippings, needles, and bits and pieces of plant material were retrieved from the soil surface below each plant and placed immediately in sealed plastic storage bags. The 50 bags were coded according to nursery, type of cultivar, and age (Table 2).

Upon return to the laboratory, fresh weights of each of the 50 individual samples were recorded. Five of the 50 samples were selected at random to be oven-dried as a basis for calculating moisture content. Samples were dried at 60C for 48 h in standard, brown-paper grocery bags. Based on the average moisture content of the five dried samples, the average yields per plant in grams (dry basis) were calculated for each field along with the standard deviation.

Discussion

Results for the 18 most-numer-

Table 2. Summary of field data obtained while sampling plants for clippings yields

Cultivar	Age (years)	Code	Field layout		Plant population		Yield/plant ² (g, db)		Moisture content (%)	
			No./row	Plants/row	Grower estimate	Actual count	Mean	SD	Mean	SD
<i>Taxus × media</i>										
‘Hicksii’	7	SH7	2	200	500	400	66.1	21.9	57.4	0.8
‘Densifformis’	3	SD3	12	325	3,100	3,900	23.6	9.8	53.4	1.3
‘Densifformis’	7	SD7	30	150	4,500	4,500	70.0	35.7	57.0	1.4
‘Runyan’	3	SR3	14	310	6,100	4,340	29.5	18.6	55.5	0.9
‘Runyan’	7	SR7	---	---	3,750	3,750	65.5	29.5	55.9	1.2
‘Hicksii’	3	BH3	---	---	---	2,750	18.8	8.1	51.3	0.9
‘Densifformis’	4	BD4	---	---	450	190	190.2	103.9	51.4	2.9
‘Densifformis’	5	BD5	---	---	1,725	1,624	135.7	62.9	49.8	1.7
‘Hicksii’	5	RH5	66	80	---	5,280	26.8	16.2	51.5	1.0
‘Hicksii’	7	RH7	14	787	---	11,018	50.5	21.7	53.7	0.5
‘Densifformis’	6	LD6	27	236	10,000	6,372	142.4	51.3	54.8	0.5
‘Densifformis’	7	LD7	36	149	6,260	5,364	60.8	26.7	55.7	0.5
‘Densifformis’	7	ZD7	---	---	---	---	50.1	20.8	53.4	0.4

²Based on average moisture content of five plants (dry-weight basis) from each sample of 50 plants.

Table 3. *Field-grown Taxus plant populations as a function of cultivar and nursery.*

Cultivar	Nursery code																	Total plants
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
No. plants (1000s), all ages																		
Taxus × media																		
'Densiformis'	211	153	12	535	87	60	---	552	310	874	11	84	154	910	333	---	4,069	8,355
'Hicksii'	113	9	2	155	39	3	69	469	34	557	10	99	288	453	108	---	2,892	5,300
'Brownii'	10	19	2	95	17	1	31	415	45	391	1	28	91	148	92	38	2,200	3,624
'Darkgreen'	---	20	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2,949	2,969
'Runyan'	---	11	---	---	36	---	---	---	---	---	11	192	490	---	---	---	887	1,627
'Wardii'	24	---	2	---	---	---	---	128	31	98	5	11	113	13	---	35	912	1,372
'Tautoni'	---	---	---	---	---	---	---	---	24	3	---	8	---	---	87	---	1,249	1,371
'Henryi'	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	630	630
'Fairview'	---	---	---	---	---	---	---	564	---	---	---	---	---	---	---	---	---	564
'Harfieldii'	136	---	---	---	---	---	---	---	8	---	---	---	---	5	123	---	---	272
'Nigra'	---	---	---	---	---	---	---	---	10	---	---	---	---	4	201	---	---	215
'Anglelica'	192	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	192
'Greenwave'	64	---	---	---	---	---	---	---	---	---	17	---	---	107	---	---	---	188
'Everlow'	---	---	---	---	11	---	---	---	---	3	---	23	---	---	---	143	---	180
'Vermuelen'	149	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	149
'Bobbink'	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	146	146
'Chadwick'	---	---	---	---	---	---	---	---	---	---	---	13	119	---	---	---	---	132
'Berryhill'	---	---	---	---	91	---	---	---	---	---	---	---	24	---	---	---	---	115
Subtotal	899	212	18	785	281	64	100	2128	462	1926	55	458	1279	1640	944	216	15,394	27,401
T. cuspidata																		
'Capitata'	40	---	1	---	---	---	---	849	---	42	1	24	---	179	86	10	2,538	3,770
No cultivar	---	---	---	---	---	---	---	56	---	---	---	---	31	6	23	---	161	277
'Nana'	112	---	---	---	---	---	---	---	---	---	---	---	---	---	63	---	---	175
'Thayerae'	---	---	---	---	43	---	---	---	---	---	---	---	119	---	---	---	---	162
Subtotal	152	0	1	0	43	0	0	905	0	42	1	24	150	185	172	10	2,699	4,384
T. baccata																		
'Rependens'	---	---	---	---	---	---	---	123	---	45	---	---	---	---	43	10	---	221
Total	1,051	212	19	785	324	64	100	3156	462	2013	56	482	1429	1825	1159	236	18,633	32,006

ous *T. × media* and the four most numerous *T. cuspidata* are tabulated in Table 3 based on responses from the 17 nurseries. *Taxus baccata* 'Rependens' also is shown. Rooted cuttings were counted as plants; cutting wood was not. The number-one cultivar in terms of total plants growing of all ages at the time of the survey was *T. × media* 'Densiformis', with a total population of 8.36 million plants. *Taxus × media* 'Hicksii' was second, with 5.30 million plants, while *T. cuspidata* 'Capitata' was third, with 3.77 million. The fourth-most-numerous plant was *T. × media* 'Brownii', with 3.62 million plants, followed by *T. × media* 'Dark Green Spreader', with 2.97 million.

Plant population by nursery and cultivar. Table 3 is a summary of all cultivars that were grown in *significant* quantities. For the purpose of limiting the complexity of this analysis, a cultivar was designated significant if 100,000 plants (or more) of the cultivar were grown in at least one of the nurseries that responded to the survey. This number included rooted cuttings, all plants ranging from 1 to 10 years old, and plants >10 years old. Cutting wood was excluded. There may be some cultivars that were left out because >40 nurseries did not respond to the census report. There also may be cultivars that were grown in small numbers (<100,000 plants) in a

number of nurseries where combined production of that cultivar would exceed 100,000 plants. Although the designation of 100,000 plants was arbitrary, it is a conservative estimate of the minimum population of plants in any one nursery that will be required to produce enough clippings to justify economically collecting, handling, drying, and storing clippings for the taxol/taxane market.

Review of Table 3 reveals that the three most-numerous cultivars, *T. × media* 'Densiformis', 'Hicksii', and 'Brownii' are grown by at least 15 of the 17 nurseries that responded to the survey. Eleven out of the 17 nurseries evaluated grew *T. × media* 'Wardii',

Table 4. *Populations of more commonly grown Taxus cultivars by age and total plants grown.*

Cultivar	Cutting wood	Rooted cuttings	Age of plants (years)											Total plants
			One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten	>Ten	
Plants (1000s)														
Taxus× media														
‘Densiformis’	370.0	1378.5	1318.8	1508.0	1492.7	866.8	952.8	400.2	260.5	105.5	67.8	2.3	---	8353.9
‘Hicksii’	368.0	990.5	903.1	888.0	632.6	538.4	516.3	216.1	227.8	124.0	130.5	91.8	40.0	5299.1
‘Brownii’	161.0	608.8	620.5	697.0	554.8	290.6	238.9	267.2	140.7	182.8	18.5	2.8	1.0	3623.3
‘Dark Green Spreader’	---	117.0	943.0	538.0	376.0	385.0	269.0	189.0	72.0	53.0	27.0	---	---	2969.0
‘Runyan’	278.4	456.4	457.0	334.0	97.8	160.5	56.1	30.5	26.8	5.8	1.3	0.8	---	1626.9
‘Wardii’	92.1	227.2	250.0	221.0	172.5	173.3	171.0	44.4	51.5	40.5	15.5	4.5	---	1371.4
T. cuspidata														
‘Capitata’	9.0	67.2	290.4	1039.4	235.5	314.3	606.6	87.8	177.3	449.5	88.2	150.1	264.0	3770.3

and 10 grew *T. cuspidata* 'Capitata'. Otherwise, most cultivars that are grown in significant quantities seem to be specialties of one or two nurseries.

Plant population by age. A summary of plant populations of more commonly grown cultivars as a function of age is provided in Table 4. A wide diversity in age of plantings is evident from the survey results. Grower estimates are subject to error; however, the survey results provide a good idea of what existing plant populations may be.

Clippings yields. A tabulation of measured and estimated clippings yields for 3- to 7-year-old plants from five nurseries is shown in Table 5 for *T. × media* 'Hicksii' and 'Densiformis' as a function of age. Table 2 provides the resource data for Table 5. Data available from Table 2 for *T. × media* 'Runyan' was not included in Table 5. The yields per plant listed in Table 2 are samples of growth that occurred during 1991. The 1991 growing season was limited by low rainfall in Ohio and surrounding states. Average rainfall in Ohio is 100 cm; in 1991, the state average was 61 cm. These yields are therefore, at best, rough estimates of expected clippings yields. The large standard deviations are evidence of the wide variation in yields among plants. The moisture contents listed in Table 2 were used to determine clippings yields on a dry-weight basis.

Referring to the codes in column 3 of Table 2, BH3 and RH5 are the only results for expected clippings yields for 3- and 5-year-old *T. × media* 'Hicksii' plants. The results given for BH3 and RH5 in column 8 (18.8, and 26.8) were rounded off to 19 and 27 g/plant (db) and recorded in Table 5. The result for 7-year-old *T. × media* 'Hicksii' plants (58 g/plant) is the average of SH7 and RH7. Expected yields for 4- and 6-year-old plants were estimated by interpolation.

For 3-, 5-, and 6-year-old *T. ×*

media 'Densiformis' plants, results from only one field each (SD3, BD5, and LD6) are available for estimating expected yields in Table 2. Again, the raw data (23.6, 135.7, and 142.4) were rounded off and entered in Table 5. The result for 4-year-old *T. × media* 'Densiformis' (BD4) was 190 g/plant. This yield was very high relative to all other results; therefore, it was excluded from the analysis. The field could have been unusually fertile or the age was improperly recorded. The yield for 4-year-old plants was, therefore, interpolated from the results for 3- and 5-year-old plants. The result for 7-year-old *T. × media* 'Densiformis' plants, 60 g/plant, is the average of three fields (SD7, LD7, and ZD7). Recognizing that these data are a rough estimate, or "first look," at expected yields, the results show clippings from *T. × media* 'Densiformis' may be more than double the expected yield of *T. × media* 'Hicksii'.

No information of this type is known to exist in nursery crop literature. Plants are pruned every year to develop compactness; i.e., a high density of limbs and branches. Clippings generally have been left to lay on the ground. If these same clippings can be harvested for taxol or taxane production, then, what was heretofore waste, now has the potential to become a second crop.

Table 6 is a tabulation of expected

clippings yields for 3- to 7-year-old *T. × media* 'Densiformis' plants as a function of age and nursery. Plants that are 3 to 7 years old would have the greatest potential as a renewable source of *Taxus* clippings because they are in the productive cycle and have to be clipped each year. The results were calculated by multiplying expected yields (Table 5) times plant populations. These results indicate that an estimated 307,208 kg (db) of clippings could have been obtained from the 15 nurseries reporting that they grew *T. × media* 'Densiformis'.

Table 7 reveals expected yields for *T. × media* 'Hicksii' that were developed by following the same procedure described above for Table 6. Comparison of the total yields for all nurseries for ages 3 to 7 years shows expected yields for *T. × media* 'Hicksii' plants are only 20% of expected yields for *T. × media* 'Densiformis'. The lower total plant population (Table 3), combined with much lower yields per plant (Table 5), lead to the lower total expected clippings yield.

Traditionally, most field crops are evaluated in terms of yields per acre. When plant populations per acre are known, the yield data in Table 5 then can be used to estimate expected yield per acre. The section entitled "Land Area Required" (see below) can be used (or customized according to plant populations grown by individual nurs-

Table 6. *Expected clippings yields per year for 3- to 7-year-old Taxus × media 'Densiformis' plants by nursery and age of plants.*

Nursery code	Age of plants (years)					Total
	Three	Four	Five	Six	Seven	
	<i>kg (db)</i>					
A	1 080	2 320	---	2,130	---	5,530
B	672	480	680	---	---	1,832
C	288	---	---	---	---	288
D	4,200	4,000	12,240	2,840	600	23,880
E	456	1,040	272	639	360	2,767
F	---	---	---	---	---	0
G	---	---	---	---	---	0
H	2,328	5,600	9,656	5,254	6,300	29,138
I	1,200	4,000	5,440	---	---	10,640
J	4,128	---	4,624	3,834	240	12,826
K	---	---	---	---	---	0
L	432	1,000	---	28	---	1,460
M	569	2,184	1,333	639	270	4,995
N	600	---	30,872	---	---	31,472
O	1,152	3,840	4,080	4,260	1,800	15,132
P	---	---	---	---	---	0
Q	18,720	44,880	60,384	37,204	6,060	167,248
Total	35,825	69,344	129,581	56,828	15,630	307,208

Table 5. *Measured and estimated clippings yields per plant per year for Taxus × media 'Hicksii' and 'Densiformis' as a function of age.*

Cultivar	Age of plants (years)				
	Three	Four	Five	Six	Seven
	<i>g (db)/plant per year</i>				
<i>Taxus × media</i>					
'Hicksii'	19	23 ^z	27	43 ^z	58
'Densiformis'	24	80 ^z	136	142	60

^zYields estimated by interpolation.

Table 7. *Expected clippings yields per year for 3- to 7-year-old Taxus × media ‘Hicksii’ plants by nursery and age of plants*

Nursery code	Age of plants (years)					Total
	Three	Four	Five	Six	Seven	
	<i>kg (db)</i>					
A	456	506	324	---	---	1,286
B	---	---	81	---	---	81
C	38	---	---	---	---	38
D	570	460	1,080	430	290	2,830
E	144	90	135	142	99	610
F	---	---	---	---	---	0
G	228	276	---	---	---	504
H	1,273	1,150	1,296	1,978	2,494	8,191
I	114	138	162	---	---	414
J	1,254	---	594	645	696	3,198
K	---	---	---	---	---	0
L	266	368	---	---	644	1,278
M	589	587	656	980	1,740	4,552
N	---	---	2,700	---	---	2,700
O	266	322	324	516	696	2,124
P	---	---	---	---	---	0
Q	6,821	8,487	6,588	4,601	6,554	33,051
Total	12,019	12,383	13,940	9,292	13,212	60,847

eries) to facilitate the estimation of clippings yields per acre.

Based on plant population and taxane yield potential from needles only (see Table 1), *T. × media* ‘Densiformis’ might appear to have promise as a viable source of 10-deacetylbaaccatin III. However, current isolation technologies cannot produce taxanes from such low concentrations cost-effectively (Croom et al., 1991). Either more-efficient chemical processing technologies must be developed, or additional compounds in high concentrations that can be converted efficiently to taxol must be found in *T. × media* ‘Densiformis’ for this material to become a viable commercial source. While *T. baccata* ‘Repandens’ is apparently the best source of 10-deacetylbaaccatin III, the results (based on the nurseries that responded to the survey) showed that only an estimated 221,000 plants currently are grown (see Tables 1 and 3). While other ornamental *Taxus* plants eventually may be identified as promising sources of taxol or taxol precursors, *T. × media* ‘Hicksii’ currently prevails as the most-ideal ornamental yew that could provide a renewable source of the drug because of immediate availability and potential for mechanically harvesting upright clippings. In addition, based on a new process developed by Croom et al. (1991) (patent pending), taxol and taxane yields for *T. × media*

‘Hicksii’ may be more than double those shown in Table 1. Even if isolated taxol yields of 0.010% to 0.014% are obtainable from *T. × media* ‘Hicksii’, Croom et al. (1991) estimate 14 to 20 kg (db) of *T. × media* ‘Hicksii’ clippings would supply enough taxol (2 g) to provide one full course of treatments for one ovarian cancer patient. Using only the *T. × media* ‘Hicksii’ clippings identified in Table 7, 3000 to 4000 patients could be treated with the taxol isolated from these clippings. The isolation and conversion of other taxanes to taxol from *T. × media* ‘Hicksii’ and other cultivars could increase taxol supplies several-fold beyond these estimates.

Land area required

Some estimate of land area required to grow various *Taxus* cultivars should be noted. As an example, when plants are transplanted to fields at about 3 years of age, Zelenka Nursery, Inc. (Grand Haven, Mich.) typically plants two rows to a bed with plants spaced 18 inches apart in the row. The rows are spaced 44 inches apart in beds that are laid out 84 inches apart. These spacings lead to a theoretical population of 8297 plants per acre. A current trend is to plant three rows in each bed with all other specifications the same as outlined above. This practice leads to a theoretical population of 12,446 plants per acre. After adjusting these

populations for turn rows, irrigation ditches, etc., reasonable estimates for two- and three-row plantings in beds may be 8000 and 12,000 plants per acre, respectively.

Sources of error

1) An attempt was made to survey all nurseries with known significant populations of *Taxus* cultivars. Such nurseries could have been overlooked, failed to receive the survey forms, lost the forms, or elected not to fill out the forms and return them. Also, no attempt was made to contact nurseries outside of the United States. In any event, the 17 nurseries referred to above may still represent 75% to 90% of all commercially grown *Taxus* in the United States; therefore, the information provided in this report would be relevant and useful.

2) There may be *Taxus* cultivars that are grown in *significant* quantities somewhere (100,000 plants or more) that are not among the plants grown by the reporting nurseries.

3) Because of historical propagation practices, growers may not know which cultivar they are growing. Plant populations within a given field may be generally one cultivar, but extraneous, unexpected cultivars may be dispersed throughout a given field. Even experts have difficulty identifying and distinguishing some cultivars.

4) Growers vary in their assessment of plant age. Some determine age based on the time when cutting wood is “stuck” and rooting is initiated. Others may refer to a 3-year-old plant based on the time it was transplanted in the field. The survey forms were laid out carefully to minimize these sources of error, but general agreement on plant age does not seem to exist.

5) Tracking plant inventory is difficult for many nursery operators. Inventory tracking requires unusual dedication because of plant mortality in the field and the standard practice of selective harvest. Some plants may be alive, but are sufficiently defective that they may not be a viable source of clippings or marketable as an ornamental plant. Accurate inventory is complicated further because of problems associated with distinguishing cultivars (referred to above).

Recommendations for future research

1) Periodically survey *Taxus* plant

populations (at least once every 5 years).

2) Focus surveys on cultivars shown to be promising sources of taxol and taxanes.

3) Continue to sample clippings yields annually for plants more than 3 years old.

4) Study the potential for harvesting other plant organs and whole plants for taxol along with clippings. Questions to be answered include: a) What would be the optimum plant age to harvest?; b) At what time of year should harvesting be done?; c) should plants be dried, after which needles only are stored and marketed?; d) how can agronomic practices be adjusted (row spacing, fertilization, irrigation, choice of climate, etc.) to maximize taxol/taxane yields per acre?; e) how does the dedicated "whole-plant-for-taxol" system compare economically to harvesting clippings and cull plants as by-products of traditional production and marketing of ornamental yews?

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The Effect of Orchard Design on Almond Fruit Set

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Additional index words. pollination, *Prunus amygdalus*, *Prunus dulcis*

Summary. Low levels of fruit set were measured in a commercial almond [*Prunus amygdalus* Batsch, syn. *Prunus dulcis* (Mill.) D.A. Webb] orchard during 3 years. Low sets may be attributed mostly to orchard design, as cultivars are distributed in contiguous rows where pollen interchange among different cultivars is not facilitated. An appropriate orchard design and proper bee management are essential for commercial yields in self-incompatible almond cultivars.

Most commercial almond cultivars are self-incompatible (Socias i Company, 1990). Because the seed is the commercial part of the fruit, fertilization must occur to obtain a crop. Efficient cross-pollination by insects, mostly honey bees, is required, and any reduction in the number of cross-pollinated flowers can reduce yield (Kester and Griggs, 1959). Consequently, maximum yield efficiency requires the presence of simultaneously blooming inter-compatible cultivars, the presence of pollinating insects, and favorable weather conditions for both adequate bee activity and pollen tube growth. In addition, the proper proportion and distribution of the cultivar combination is necessary for efficient transport of pollen from one cultivar to another.

Although these facts are widely recognized (Traynor, 1993), some new orchards are established without con-

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