UNIVERSITY OF IDAHO
COLLEGE OF FORESTRY, WILDLIFE
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PROGENY-PROVENANCE TEST of *Pinus taiwanensis* Hay

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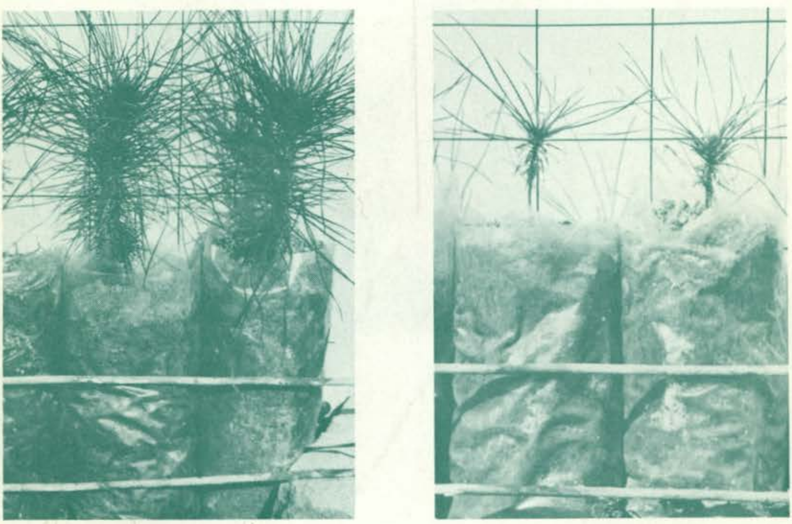

Fig. 1. Left, progeny no. 3-5, 16 month. Altitude of seed origin, 1180 m.
Right, progeny no. 4-7. Same age. Alt. 1200 m.

Forest, Wildlife and Range
Experiment Station
Moscow, Idaho

Station Paper No. 11

December, 1972

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This experiment included twenty-four progenies of *Pinus taiwanensis* Hay. Taiwan red pine from eight national-forest regions throughout the natural range of this species. The primary purpose was to investigate the intra-species variation as a basis for genetic improvement. We accomplished this by observing the variation of geographic seed sources under uniform growth conditions, by analyzing the "among-stand" and "within-stand" components of variance in the natural population, and by evaluating the site x progeny interaction at different elevations.

Results of early seedling growth indicated marked differences among progenies and provenances. The estimated components of variance showed a much larger porportion of variation in growth rate attributable to "among-stand" sources than to "within-stand" sources. In the three plantations there were distinct differences in seedling growth, but progenies maintained the characters of geographic seed origins.

MATERIALS AND EXPERIMENTAL DESIGN

The natural range of distribution of *P. taiwanensis* in Taiwan is from 700 m to 3200 m. For this study, seeds were collected from nine natural stands at elevations from 900 m to 2450 m (Table 1). Each stand was represented by one to five trees. They were dominant or codominant trees without obvious defects.

Seeds were sown in December 1970 in three nurseries close to the planting sites in individual 6 x 12 cm cylindrical plastic containers arranged in 10-replicate seed beds. At the beginning of the second growing season the seedlings were outplanted at three elevations: (1) 450 m (Taipei District Nursery, Lat. 121° 35"N Long. 24° 55"E), (2) 1050 m (University Forest, 120° 45"N, 23° 42"E), and (3) 2305 m (University Farm, 121° 10"N, 24° 05"E). Each plantation consisted of eight complete replicates of randomly arranged 4-tree plots at 3.3 m spacing.

The seedling characters observed at 16 months included seedling height, stem diameter, number of lateral buds, and length of secondary needles. Analysis of variance indicated that the differences in the above characters were significant at the .01 level in the three plantations.

* Published with the approval of the Director of Forest, Wildlife, and Range Experiment Station, University of Idaho, Moscow, Idaho. Part of the materials presented herein was reported at the Sino-U.S.A. Cooperative Seminar on Forest Ecology and Genetics, National Science Foundation, 1972.

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TABLE 1. Geographic origin of seed sources and plantation progeny means of 16-month seedling height and stem diameter.

Progeny	Stand	Altitude (M)	Lat°N	Long°E	Seedling Height (mm) 450M	1050M	2305M	Mean	Seedling Diameter (mm) 450M	1050M	2305M	Mean	Forest Region
1-1	1	900	120°52′	24°16′	86.3	100.3	116.8	101.0	2.3	2.5	2.7	2.5	Ta-Hsue-Shan
1-3	1	900	"	"	88.3	118.6	125.1	110.7	2.3	3.1	2.4	2.6	"
1-5	1	900	"	"	77.8	134.4	110.5	107.6	2.2	3.5	2.6	2.8	"
1-6	1	900	"	"	87.5	122.0	137.0	115.5	2.2	2.6	2.6	2.5	"
1-8	1	900	"	"	83.6	136.9	119.4	113.3	2.5	3.4	2.5	2.8	"
2-2	2	910	120°45′	24°09′	70.9	109.0	145.1	108.4	2.4	2.7	3.0	2.7	Ta-Chai
2-4	2	950	"	"	77.8	140.1	110.3	109.4	2.3	3.5	2.4	2.7	"
3-1	3	1180	121°07′	24°02′	108.6	121.1	132.8	120.8	2.6	3.1	2.6	2.8	Pu-Li
3-2	3	1180	"	"	134.8	157.3	188.7	160.3	2.9	3.7	3.1	3.2	"
3-5	3	1180	"	"	76.6	121.4	117.0	104.9	2.5	3.1	2.5	2.7	"
4-2	4	1200	121°22′	23°25′	53.3	80.0	69.6	67.6	1.9	2.9	2.0	2.3	Yue-Li
4-4	4	1200	"	"	42.8	88.5	72.6	68.0	1.8	3.1	2.2	2.4	"
4-7	4	1200	"	"	41.6	77.3	89.6	69.5	1.6	2.9	2.4	2.3	"
5-4	5	2000	121°08′	24°27′	47.5	78.3	88.1	71.3	1.8	2.5	2.1	2.1	Chu-Tung
6-1	6	2200	121°12′	23°43′	33.4	73.4	85.8	64.2	1.7	2.4	2.2	2.1	Luan-Ta
6-2	6	2250	"	"	35.6	72.0	67.0	58.2	1.7	2.4	2.1	2.1	"
6-3	6	2250	"	"	34.9	72.1	63.6	56.9	1.6	1.9	2.1	1.9	"
6-4	6	2250	"	"	39.3	54.9	70.1	54.7	1.8	1.8	2.1	1.9	"
7-4	7	2250	121°30′	24°25′	31.9	51.6	77.2	53.6	1.6	2.3	2.2	2.0	Lan-Yang
8-2	8	2300	121°20′	24°10′	41.5	52.5	74.3	56.1	2.0	2.1	2.1	2.1	Mu-Kua
8-3	8	2300	"	"	42.3	63.3	68.8	58.1	1.9	2.7	2.2	2.3	"
8-4	8	2300	"	"	47.9	75.1	85.9	69.6	2.0	2.8	2.3	2.4	"
9-5	9	2400	121°12′	23°43′	36.2	70.8	61.0	56.0	1.6	2.3	2.1	2.0	Luan-Ta
9-7	9	2450	"	"	36.4	66.3	62.9	55.2	1.6	1.8	2.0	1.8	"

TABLE 2. Analysis of Variance of seedling height and stem diameter of *Pinus taiwanensis* hay.

Source of Variation	Degrees of Freedom	F-Value Seedling Height 450m	1050m	2305m	Stem Diameter 450m	1050m	2305m
Replication	7	2.9027**	7.6432**	2.4719*	5.2479**	9.3656**	1.6729
Treatment	(23)	72.1520**	17.1055**	30.6098**	2.2433**	9.8384**	4.9166**
Provemance	8	15.4166**	13.3412**	8.3552**	26.7647**	4.2566**	4.9583**
Family (F)	(15)	11.9964**	3.2320**	8.0023**	0.9908	4.6131**	2.0685*
F1	4	1.6957	3.7463**	2.8547*	0.9935	6.6750**	0.8806
F2	1	2.1780	8.4604**	17.2340**	0.4664	10.7203**	8.9722**
F3	2	79.5787**	7.5457**	40.5666**	2.7806	3.2316*	5.5488**
F4	2	3.8864*	0.6008	3.3088*	1.6747	0.3786	2.7734
F6	3	0.5947	1.3632	2.7366*	0.4028	3.6759*	0.1038
F8	2	1.1348	2.2371	2.1843	0.1502	4.6692*	0.7123
F9	1	0.0011	0.1768	0.0522	0.0055	4.1876*	0.1525
Error	161						
Total	191						

* Significant at the 5 percent level. ** Significant at the 1 percent level.

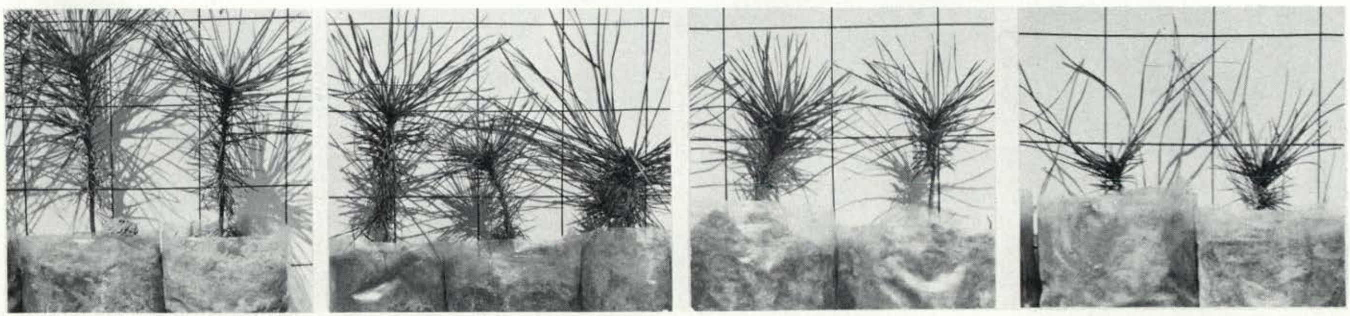


Fig. 2. Geographic Variation of *Pinus taiwanensis* Hay.
16-Month Height Growth. (1/4 x) 450 m plantation.
From left to right: stand No. 2 (progeny No. 2-4 950 m), stand No. 5 (progeny No. 5-4 2000 m), stand No. 7 (progeny No. 7-4, 2250 m), and stand No. 9 progeny No. 9-7, 2450 m).

SEEDLING HEIGHT

Seedling height, as measured from the base of stem to the tip of terminal bud was the most striking of provenance differences. Fast-growing geographic sources were nearly three times higher than the slow-growing sources at the end of the first growing season.

Analysis of variance indicated that the "among-stand" and "among progeny" differences were significant at the .01 level, at each of the three elevations (Table 2), and in the combined analysis of the three plantations (Table 3). The major disjunctive "among-stand" difference was found between the group of three fast-growing stands (Nos. 3, 1, and 2) and the group of six slow-growing stands (Nos. 5, 4, 8, 6, 9, and 7). With only minor modifications, the rankings of the stand performance remained essentially the same (Table 4).

No significant "among-stand" difference was found among the six slow growing stands. But one fast-growing stand (No. 3) was so outstanding at the low elevation (450 m) that its difference with stands 1 and 2 was highly significant (Table 4).

STEM DIAMETER

In the "among-stand" and "within-stand" differences the pattern of stem diameters variation was essentially the same as that of seedling height in the

TABLE 3. Analysis of Variance of three Altitudinal plantations of *Pinus taiwanenis* hay.

Source of Variation	Degrees of Freedom	F-Value	
		Seedling Height	Stem Diameter
Sites (S)	2	82.9669**	43.8904**
Replication	21	5.3919**	6.1704**
Treatment (T)	(23)	76.0065**	19.0837**
Provenance (P)	8	17.8300**	14.7380**
Family (F)	(15)	11.0895**	3.3026**
F1	4	2.7378*	2.9254*
F2	1	0.0489	0.1025
F3	2	70.7750**	10.9163**
F4	2	0.0834	0.3717
F6	3	1.4215	1.7204
F8	2	4.6657**	3.7168*
F9	1	0.0288	2.5585
SxT	(46)	3.0959**	3.0261**
SxP	16	0.7380	1.0850
SxF	(30)	3.4063**	2.9394**
SxF1	8	3.4769**	4.0903**
SxF2	2	16.1720**	11.8745**
SxF3	4	3.9764**	0.2765
SxF4	4	2.7524*	1.8787
SxF6	6	1.9161	1.9800
SxF8	4	0.8246	1.8902
SxF9	2	0.1598	1.8229
Error	483		
Total	575		

* Significant at the 5 percent level. ** Significant at the 1 percent level.

combined analysis of three altitudinal testing plantations (Table 3), but the "among-families"-"within-stand" difference was less distinct within individual plantations (Table 2).

The major disjunctive difference among the stands was located between the group of three fast growing stands (Nos. 3, 1 and 2) and the group of six slow-growing stands (Nos. 4, 8, 5, 7, 6 and 9). Within the group of fast-growing stands the outstanding stand No. 3 was significantly different from stands Nos. 1 and 2 (Table 4).

TABLE 4. Rankings and Multiple Range test of Seedling Height and Stem Diameter.

(A)
16-Month Seedling Height
3 Altitudinal Plantations

Rankings	Stand No.	Forest Region	Stand Mean
1	3	Pu-Li	128.69
2	1	Ta-Shue-Shan	109.61
3	2	Ta-Chai	108.90
4	5	Chu-Tung	71.28
5	4	Yue-Li	68.36
6	8	Mu-Kua	61.28
7	6	Luan-Ta	58.50
8	9	Luan-Ta	55.58
9	7	Lan-Yang	53.58

(B)
16-month Seedling Height
450 m Plantation

Stand No.	Stand Mean
3	106.68
1	84.66
2	74.39
5	47.51
4	45.92
8	43.91
9	36.31
6	35.79
7	31.94

(C)
16-month Seedling Height.
1050 m Plantation

Stand No.	Stand Mean
3	133.25
2	124.56
1	122.43
4	81.92
5	78.25
9	68.50
6	68.09
8	63.63
7	51.63

(D)
16-month Seedling Height.
2305 m Plantation

Stand No.	Stand Mean
3	146.15
2	127.74
1	121.74
5	88.06
4	77.25
7	77.18
8	76.32
6	71.61
9	61.92

(E)
16-Month Stem Diameter.
3 Altitudinal Plantations

Stand No.	Stand Mean
3	2.89
2	2.72
1	2.62
4	2.31
8	2.23
5	2.12
7	2.03
6	1.98
9	1.90

——— Means connected with solid bars are not significantly different at the 0.05 level.

ESTIMATED COMPONENTS OF VARIANCE

In general, sixty to over seventy-seven percent of the total variance in seedling height was attributable to "among-stand" sources, and only ten to twenty percent to "within-stand" sources. A similar ratio of "among-stand" and "within-stand" components was found in stem diameter (Table 5).

There was obvious uniformity in height growth and tree form among progenies of common geographic sources (Fig. 3). In the combined analysis of variance of three plantations "among-progeny" differences were significant within stands Nos. 1, 3 and 8, but no significant "among-progeny" differences were found within stands Nos. 2, 4, 6 and 9. The high ratio of "among-stand" and "within-stand" components indicated that in this species far greater variation could be expected among trees from different geographic areas than within a restricted area.

TABLE 5. Estimated Components of Variance (%) of Seedling Height and Stem Diameter of *Pinus taiwanensis* Hay.

Estimated Components of Variance	Seedling Height 450 m	Seedling Height 1050 m	Seedling Height 2305 m	Seedling Height 3 Plantations	Stem Diameter 3 Plantations
Among Stands	77.8	60.0	61.0	67.9	39.9
Within Stands	12.8	8.7	19.0	9.5	5.3

SITE INFLUENCES

The difference in elevation and related site conditions exerted a profound influence on seedling growth. The "among-plantation" differences in seedling height and stem diameter were significant at the .01 level (Table 3). At the 6-month stage the 450 m plantation was the tallest in mean seedling height, and the 2305 m plantation was the shortest. But at the 16-month stage the 450 m plantation became the shortest and the 2305 m plantation the tallest (Table 6).

TABLE 6. Plantation Mean Seedling Height and Stem Diameter

Plantations	450 m	1050 m	2305 m
6-month Seedling Height. (mm)	59.49	57.09	53.97
16-month Seedling Height. (mm)	60.70	93.20	97.45
16-month Stem Diameter (mm)	2.03	2.70	2.36

______ Means connected with bars are not significantly different at the 0.05 level.

– – – – – Means connected with dotted lines are significantly different at 0.05 level, but not significantly different at the 0.01 level.

The site x seed-source interaction was primarily at the site x progeny level. There was no significant site x provenance interation (Table 3). The relative performance in the seedling height and stem diameter of the geographic seed sources as indicated by rankings of stand means was essentially the same in the three plantations irrespective of the 1800 m difference in altitude (Table 4).

GEOGRAPHIC AND ALTITUDINAL VARIATION OF SEED SOURCES

The performance of seed sources revealed a distinct geographic and altitudinal pattern of variation. Among the nine natural stands three geographic groups are recognizable:

1. A group of fast-growing low elevation seed sources from the western watershed of the central region. This group was represented by stands Nos. 1, 2, and 3. They covered an altitudinal range of 900-1180 m.

2. A stand of slow-growing low elevation trees from the eastern watershed of the southern region. This is stand No. 4, from the Yue-Li Forest Region (1200 m). In growth rate this stand was significantly different from the first group of low elevation seed sources, but not significantly different from the next group of high elevation seed sources.

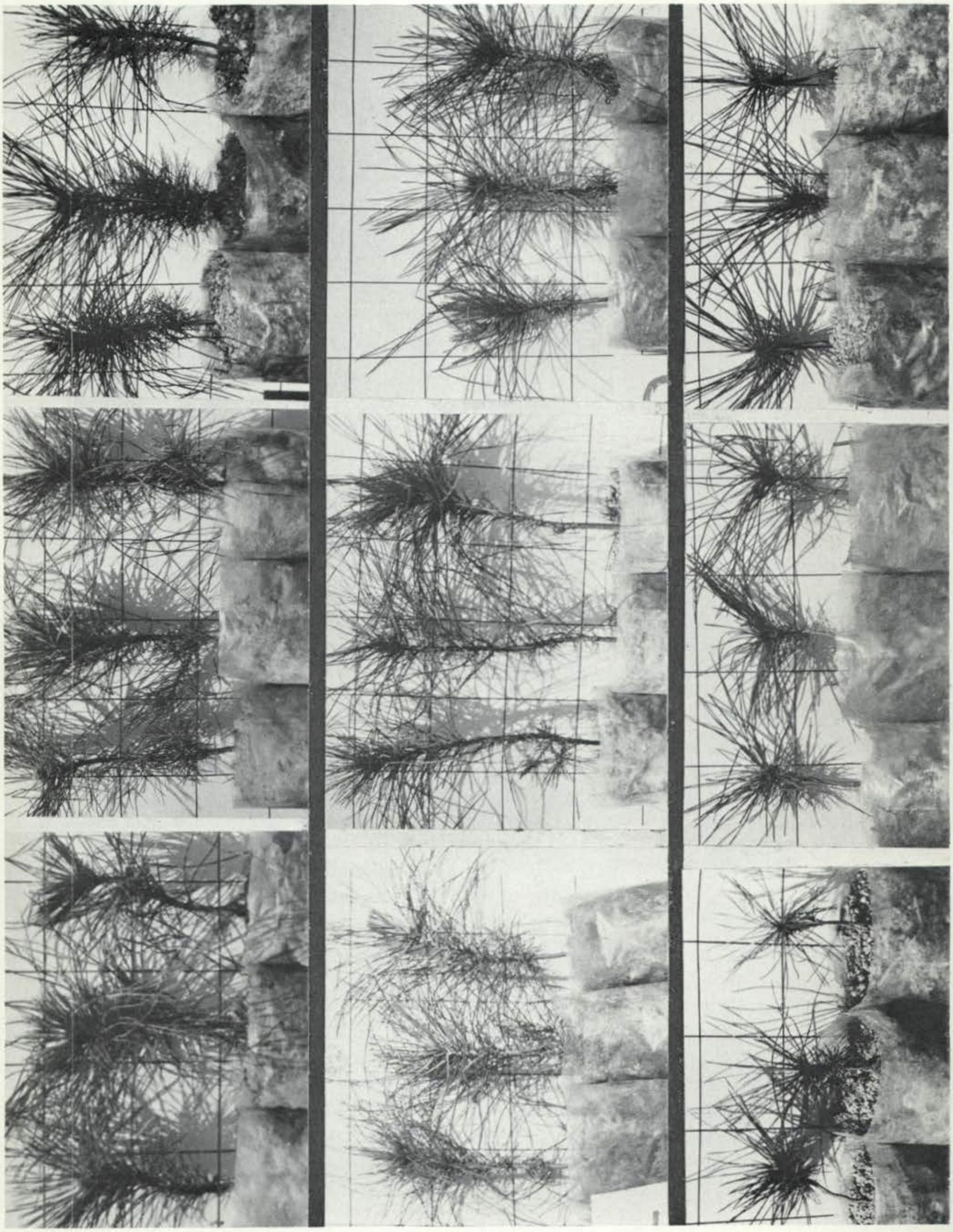
3. A group of slow-growing high elevation seed sources from both sides of the Central Divide, between 2000 and 2450 m in altitude. This group includes stands Nos. 5, 6, 7, 8 and 9.

There was a distinct negative correlation between early seedling growth and the altitude of seed origin. The group of low elevation seed sources outgrew the others at all three elevations, 450 m, 1050 m, and 2305 m at the 16-month stage. They sustained light frost damage at the 2305 m plantation.

DISCUSSION

This study was planned to demonstrate intra-species variation of a forest tree species, and to develop basic knowledge related to the natural population and its improvement. This is the first progeny and provenance test for an indigenous forest tree of this region. The wide range of geographic variation exceeded fondest expectations. Seedlings of the fast-growing seed sources were nearly three times faster in height growth than the slow-growing seed sources. Difference in growth rate of this magnitude promises substantial improvement through further progeny and provenance selections.

In the three altitudinal test plantations at 450 m, 1050 m, and 2305 m respectively, the seed source differences consistently reflected the characters of the geographic seed origin. There was no significant site x provenance interaction. Furthermore, the estimated components of variance indicated that a much larger proportion of total variance was attributable to the "among-stand" sources than to the "among-progeny"-"within-stand" sources. From the practical point of view the high ratio of "among-stand" and "within-stand" components indicated that selection of geographic seed sources would be a more rewarding initial step for genetic improvement than phenotypic selection of individual trees within a limited population of unknown merit.



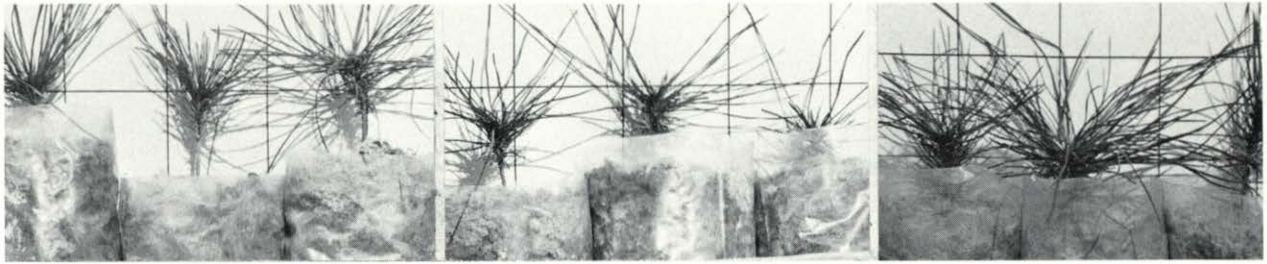


Fig. 3. "Among stand" and "within-stand" Variation of *Pinus taiwanesis* Hay. 16-Month Height Growth (1/4x) 450 m plantation.
Top row, Stand No. 1 (900 m), from left to right, progeny Nos. 1-1, 1-3, 1-8. Second row, stand No. 3 (1180 m), progeny 3-1, 3-2, and 3-5. Third row, stand No. 8 (2300 m), progeny Nos. 8-2, 8-3 and 8-4. Bottom row, stand No. 6 (2200 m), progeny Nos. 6-2, 6-3, and 6-4.