A Provenance Test of White Elm (Ulmus pumila L.) in China

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Summary

A study on the provenances indicated that the main economic and adaptative characteristics of White elm showed a clinal pattern in the direction of latitude. For example, the provenances at the Yellow River and Huai River valley in the south of the natural range grew fast with good stem form, large leaves and long growing period while those in the north-east and northwest of the natural range showed the contrary. This geographical variation pattern had a base of strictly ecological adaptability. Rational utilization of this geographical variation may obtain additional economic gains from the newly-built stands, which can testify the practical significance of this study.

Key words: White elm, geographic variation, seed source, provenance test, clinal pattern.

Zusammenfassung

Ein Provenienz-Versuch mit sibirischer Ulme (*Ulmus pumila* L.) in China.

Die Untersuchung der Provenienzen weist daraufhin, daß die wichtigen wirtschaftlichen und adaptiven Eigenschaften der sibirischen Ulme ein klinales Muster mit dem Breitengrad aufweisen. Beispielsweise wachsen die Provenienzen aus den Tälern des Gelben und des Huai-Flusses im Süden des natürlichen Verbreitungsgebietes schnell, mit guter Stammform und großen Blättern während einer langen Wachstumsperiode, während Provenienzen aus dem Nordosten und Nordwesten des natürlichen Verbreitungsgebietes das gegenteilige Verhalten zeigten. Dieses geographische Variationsmuster hat eine Grundlage in der ausgeprägten ökologischen Anpassungsfähigkeit der Art. Eine vernünftige Nutzung dieser geographischen Variation kann zu erheblichen wirtschaftlichen Gewinnen aus den neu zu errichtenden Beständen führen. Die praktische Bedeutung dieser Untersuchungen kann außerdem auf diese Weise kontrolliert werden.

Introduction

White elm is one of the major tree species for the timber, shelter, food and fodder in east Asia. It is widely distributed over China, The People's Republic of Mongolia, The Democratic People's Republic of Korea and the Asian part of the Soviet Union. Since the 1940s, it has been widely introduced to the arid areas in the Soviet Union, the United States of America and Canada as a tree species for sherterbelts (TINUS, 1976; VOROBIEV, 1978; WEBB, 1948). Many European countries introduced it as a gene resource for breeding resistance to Dutch elm disease (D.E.D.) (SANTAMOUR, 1974; SINCLAIR, 1978). In Chinese long history, White elm has been an important traditional source of hard wood for farm tools and buildings. At the same time, it is also called domestic elm and widely cultivated (HEYBROEK, 1979; ZHENG, 1978) because its tender leaves, young fruits and edible bark are used as a food of the peasents in some areas. With the development of tree fodder industry, the feeding value of White elm has drawn greater attention from the forestry circle MCKELL, 1978; MOORE, 1967). Consequently, in the recent two decades White elm has been widely developed in China, some 200,000 kg seed of White elm are transferred from the major cultivation regions to the other areas every year. Since there are great differences in growth ability, cold-resistance and drought-resistance (LONG, 1971; SUEDKAMP, 1976), afforestation would fail if we could not give consideration to these differences when introducing exotic seeds. In order to suit the needs of developing White elm, besides establishing seed orchards and conducting clonal breeding, we also began the provenance test of White elm from 1979, with the national cooperative experiences on the study. In this paper we present simply primary results to meet demand from various field.

The purpose of this study was: (1) to reveal the geographical variation patterns of the major characteristics of white elm; (2) to find out the most suitable seed source for afforestation in different ecological regions in China.

White elm has its natural distribution from the northern subtropical zone to the cold temperate zone which is approximately at 32° to 53° north latitude, 74° to 134° east longitude, 3 m to 3650 m above sea level (*Fig. 1*). In this range, the annual mean temperature is about −4° C to +15° C, extreme lowest temperature being −52.3° C and extreme highest 48° C; the frost-free season is 80 days to 240 days, actively accumulated temperature (> 10° C) being between 1100° C to 4500° C; annual rainfall is 16 mm to 1200 mm. These great differences of the climatic factors and the history of artificial cultivation at various area in the natural range give rise to the expectation of substantial genetic variations related to geographic origins.

Materials and Methods

Collection and Allocation of Materials

In this study 48 sedlots were collected from 16 provinces throughout the part of natural range of White elm in China in 1980 (*Fig. 1* and *Table 1*). The principles for determining the collection locations were: (1) Collection positions were arranged according to the coordinate of longitude and latitude of range so that they had the most ratinal ecological and regional representative; (2) Collection positions were selected mostly at the high productive areas with long cultivation history such as the lower valley of Yellow and Hai River so that the superior provenances could be selected for most sites in which test plantations were established. In order to guarantee the genetic diversity of seeds used in this test, parent trees were selected at random at several communes or villages in each location as unit of seed collection. Every seedlot consisted of 20 parent trees and seeds were collected separately. Quality test of seeds used in the study were conducted by the department of tree breeding and genetics of the Chinese Acadenmy of Forestry and then distributed to the members of the cooperative group. At first, equal quantities of seeds per mother tree belonging to same

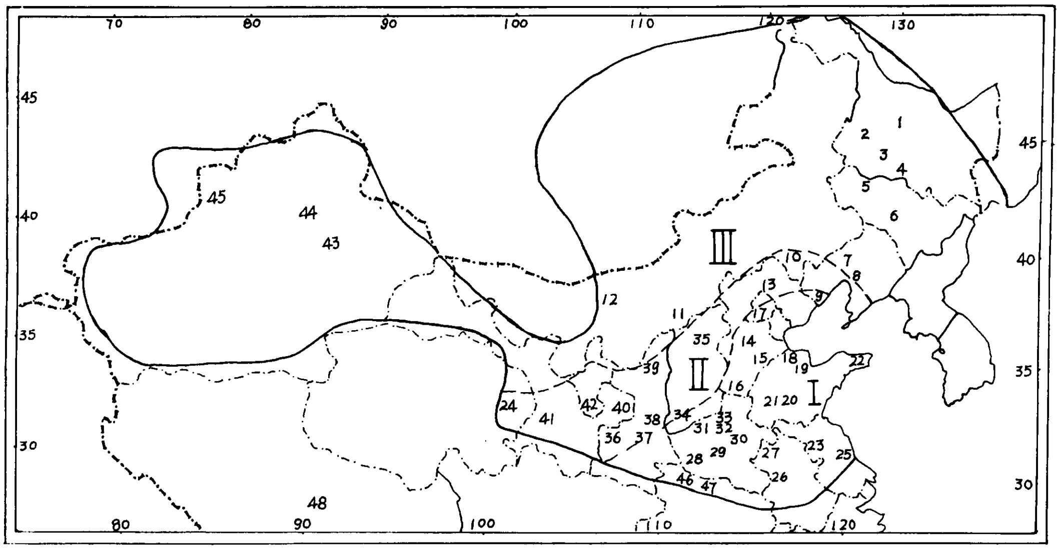


Figure 1. — Distribution, locations of seedlots and geographic groupings of provenances of White elm in China.

seed source were mixed for the provenance tests. Then the residual seeds per tree as a family were allocated separately to several cooperators for progeny tests to reveal family variation within provenance.

Nursery Procedure

The seedlings were grown for two years in 25 experimental nurseries belonging to 13 provinces in north China. The seeds were sown in the early summer 1980, 3 to 5 row plots arranged in a randomized complete block design and replicated 4 to 5 times at first year. In the second year the one-year old seedlings were transplanted in the same nursery in a randomized complete block design with plots of 3 rows and 10-trees per row. There were 6 replications. The surplus seedlings were planted in other beds for test plantations established in the next year.

Plantation Establishment

In each field experiment a square plot with 9 trees in 4 m × 4 m or 4 m × 3 m spacing adopted. A randomized complete block design with 6 replications was used. To provide protection against damage from animals, 1 to 2 row surrrounding trees around the plantation were planted. A total of 25 plantations was established in 1982 at 13 provinces (autonomous regions).

Observations and Measurements

The observed items in the nursery stage were: height, root collar diameter, number of branches per 50 cm stem length of 2-year seedlings, size of leaves, withering length of branches and percentage dieback after winter, annual growth rhythm and ratio in length of lateral branches vs total height 2-year seedlings, biomass of seedlings (fresh and dry weight above and undergroud parts). In the field test, the height and DBH in the consecutive years, form and property of stem, branching habit, moisture content of leaves and twigs, phenological phases were observed and measured.

Data Analysis

The data used in this paper are derived principally from plantation established at Beijing and only a few from some ecologically representative plantations in other provinces. Analysis of various measurements, single correlation and partial correlations between the topographical variables and characteristics above mentioned, topographical variables and meteorological elements of each location of seed collection were calculated. For classification of geographical group, analysis of the principal component and cluster of seven important independent parameters obtained from each provenance were carried out.

Results and Analysis

Characters of the Seeds and the Seedlings

A study on oven-dry weight of 1000 seeds, length of the hypocotyl and primary root was carried out when the seed shells dropped during the germination period and notable differences among the provenances were found. For example, the weight of the 1,000 seeds ranged from 4.6 g to 7.9 g (the F value was 4.0**); the length of hypocotyl ranged from 2.87 cm to 3.76 cm (F being 6.47**); the length of primary root ranged from 2.0 cm to 3.9 cm (F-value of 7.8**). But the variation of these three characters had no geographical tendency. The data in *table 2* shows the correlation coefficient between various natural variables of the seed sources and the measured characteristics (represented by r).

Height and DBH

The height growth and the DBH was measured every year at all the plantations. The data of the 8 typical ecologically representative plantation are shown in *table 3* and *4*.

The data in *table 3* and *table 4* indicated that average DBH and height of trees from all seed sources had significant difference. The results of the comprehensive variance analysis (*table 5*) which were carried out in Liaoning province indicate that differences arising from provenances took very great portion in the total component of variance, i.e., 51.3% to 87.6% of the height variations were caused by provenances. Although the interaction between the prrovenance and site had certain ratio, yet it was much smaller. Therefore, there is potential to select superior provenances through provenance tests for afforestation.

Table 1. — Locations and climates of seed sources included in the trial.

No.	Provinces	Counties	latitude (°N)	longitude (°E)	Elevation (M)	Annual mean temperature (°C)	Annual rainfall (mm)
1	Heilungkiang	Bei An	48.3	126.5	269	0.5	461.1
2		Chichihal	47.4	123.9	145	3.1	451.5
3		Chaotung	46	127	147	2.6	258.2
4		Shuangcheng	45.5	126.3	166	4.6	424.7
5	Kirin	Da An	45.5	124.3	137	4.3	409.2
6		Changchun	43.9	125.2	236	4.8	610.8
7	Liaoning	Xin Min	42	122.8	30	7.5	607.5
8		Shen Yang	41.8	123.4	41	7.7	755.4
9		Xing Cheng	40.6	120.7	88	8.6	594
10	Inner Mongolia	Chi Feng	42.3	119	571	6.6	371.6
11		Ching Shui He	39.9	111.7	1300	6.9	416.1
12		Wu Yuan	41	108.3	1023	5.7	173.9
13	Hopei	Cheng De	41	117.8	375	9	566.5
14		Bo Ye	38.5	115.5	50	12.3	506.7
15		Gu Cheng	37.3	116	27	12.9	575,4
16		Wei Xian	36.3	115	56	13.2	417.4
17	Beijing Municipality	Hai Dian	40.4	116.8	73	11.6	584
18	Shantung	Lao Ling	37.7	117.2	11	6.9	63
19		Guang Rao	37	118.3	14	12.2	637.3
20		Yan Chow	35.6	116.8	51	13.5	740.7
21		Ji Ning	35.5	116.6	41	13.4	724.2
22		Wing Deng	37.2	122	54	11.1	856.9
23	Kiangsu	Si Yang	33.7	118.7	14	14.2	892
24	Chinghai	Si Ning	36.6	101.9	2261	5.7	371.7
25	Kiangsu	Yan Cheng	33.4	120	2	14.2	1112.1
26	Anhwei	Hue Qiu	32.3	116.3	32	15.4	951.3
27		Guo Yang	33.5	116.2	30	14.6	841.8
28	Honan	Deng Xian	32.7	112	111	15.4	698,5
29		Wu Yang	33.5	113.6	91	14.6	833.2
30		Chi Xian	34.5	114.8	59	14.1	713.5
31		Mong Xian	34.9	112.8	116	14.2	617.5
32		Huo Jia	35.3	113.7	76	14.4	588.9
33		Jiao Zuo	35.2	113.3	112	14.9	607.9
34	Shansi	Yuen Cheng	35	111	367	13.4	553.1
35		Xin Xian	38.3	112.8	800	8.8	380
36	Shensi	Mei Xian	34.3	107.7	530	12.9	606
37		Hua Xian	34.5	109.7	341	13.4	602
38		Da Li	34.9	109.9	367	13.3	538
39		Yui Lin	38.2	109.7	1057	8.1	438.4
40	Kansu	Ching Yang	36	107.7	1421	8.3	570
		Lan Chow	36	103.9	1571	8.9	331.5
41	Ninghsia	Gu Yuan	36	106.3	1753	6.3	503.8
43	Sinkiang	Tuloufan	42.9	89.5	35	14.1	16.6
44		Wu Lou Muchi	43.9	87.5	918	7.3	194.6
45		Yi Li	44	81.3	662	8.2	263.7
46	Hupei	Xiang Fan	32	112.1	68	15.8	878.4
47		Zao Yang	32	112.4	400	15.4	870
48	Tibet	La Sa	29.7	91	3650	7.1	463.3

The Biomass above and under Ground and its Distributional Tendency

The study of the variations of the biomass in different seed sources and at different parts of plants not only reveals the overall differences of the growth ability among different origins but also helps to know the distributional direction of photosynthetic products within trees from various origins and provides information for genetic improvement. This study was carried out by selecting twenty seedlings from each of the 20 representative provenances and planting them in pottery pots. By the end of growing season the dry and fresh weight of their above ground parts and roots were weighed and their length was measured. The dry weight ratio of them among provenances are shown in *Figure 2.*

From *Figure 2* it can be seen that the roots of the seedlings of White elm were heavier than the stems and the dry weights of the above ground part and the underground part in different provenances were greatly different. For instance, the root weight of the various provenances at the valley of Yellow River and Huaihe River in central China was about 1.5 times the stem weight, but in the northern provenances this figure exceeded 2.0 to 2.5. The correlation coefficient between the dry weight ratio of the above ground part in the total weight of the whole tree and the latitude of the origins was -0.8430^{**} but the

Table 2. — Correlation between weight of the 1000 seeds, seedling characteristics and the natural variables of origins.

R / Natural variable / Characteristics	Lat.	Long.	Elevation	Annual mean temperature	Annual rainfall
Length of primary root	0.1395	0.1329	−0.1192	0.0667	−0.0187
Length of hypocotyl	0.1945	0.0534	−0.1408	0.0550	−0.0464
Weight of the 1000 seeds	0.0324	0.0993	−0.1019	0.1053	−0.1925

Non of the correlation coefficient was statistically significant

Table 3. — Differences (F value) at different ages and the range of mean height among origins at 6-years of age from 8 plantations.

Age / Plantations	1981	1982	1983	1984	1985	Range of seed source means (m)
Beijing Municipality	13.2**	4.78**	7.47**			3.6 - 7
Xing Cheng County, Liaoning Province	3.25**	3.63**	4.75**	7.66**	9.09**	4.4 - 6.9
Zhuang He County, Liaoning Province	4.85**	8.45**	4.48**	10.77**	8.54**	5.0 - 6.5
Xin Min County, Liaoning Province		3.47**	2.66**	2.87**	2.96**	4.3 - 6.3
Hu He How Te Municipality	8.5**	4.25**	6.86**	7.84**	4.24**	3.1 - 6.1
Lan Chow Municipatily	10.67**	6.75**	14.32**	12.61**	10.71**	3.1 - 4.6
Hua Long County, Chinghai Province			2.41**	2.42**	2.12**	1.9 - 4.2
Yan Chow County, Shatung Province				15.07**	17.9**	5.5 - 8.4

* significant at the 5 percent level
** significant at the 1 percent level

Table 4. — Differences (F value) at different ages and range of DBH among origins at 6-years of age from 8 plantations.

Age / Plantations	1981	1982	1983	1984	1985	Range of seed source means (cm)
Beijing Municipality	9.0**	8.36**	6.1**			1.9 - 4.6
Xing Cheng County, Liaoning Province	3.22**	3.59**	4.52**	6.89**	6.16**	5.2 - 8.1
Zhuang He County, Liaoning Province	4.85**	8.45**	3.7**	5.85**	6.13**	4.9 - 8.4
Xin Min County, Liaoning Province			3.42**	2.99**	2.51**	4.7 - 8.0
Hu He How Te Municipality	10.0**	3.11**	2.69**	1.92**	2.74**	3.2 - 6.9
Lan Chow Municipality	3.89**	3.89**	8.85**	12.15**	8.55**	3.4 - 4.9
Hua Long County, Chinghai Province			2.11**	2.76**	2.05**	0.9 - 3.8
Yan Chow County, Shatung Province				7.68**	3.53**	8.3 - 11.5

* significant at the 5 percent level
** significant at the 1 percent level

Table 5. — The variance components and F value of growth (H, DBH) in the multiple site tests of White elm.

Source of Variation	Expected Mean Square	Charac-teristics	1983 Component of variance (%)	1983 F value	1984 Component of variance (%)	1984 F value	1985 Component of variance (%)	1985 F value
Sites (S)	$\sigma^2+P\sigma^2_{R+}+PR\sigma^2_S$	H	7.9	155.8**	0.9	20.1**	7.0	31.0**
		DBH	1.0	30.1**	2.5	43.8**	0	1.3**
provenances (P)	$\sigma^2+RS\sigma^2_P$	H	51.3	6.1**	87.6	11.3**	78.4	12.3**
		DBH	69.7	4.1**	91,5	8.5**	62.5	7.4**
Site × Prov. (S × P)	$\sigma^2+R\sigma^2_{PS}$	H	36.2	1.6**	7.4	1.1	17.4	1.4**
		DBH	21.1	1.5**	0.2	1.0	32.4	1.5*

* significant at the 5 percent level
** significant at the 1 percent level
The variance components for replications within sites (Error a) and provenances × replications within locations (Error b) are not given in this table.

root weight was on the contrary. This indicated that more photosynthetic products of the southern seedlings were used to form the stems than those in the northern. This was one of the reasons that the seedlings of the southern provenances grew faster and the northern provenance appeared more adapted to thte severe conditions.

Form and Quality of the Stem

Significant difference in the straightness and quality (with or without visual main stem in the part of crown) of the stem of the 6-year-old trees from different origins existed. For example, in the plantation at Beijing the percentage of crookedly stemed trees among the 48 origins

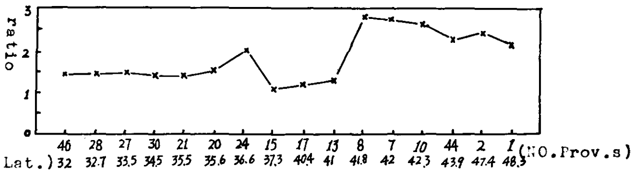


Figure 2. — Ratio under/above ground part in dry weight.

ranged from 24% to 100%. Usually trees from the southern provenances are not only low in crooked trunk percentage but also good in the quality of stem. The trees from northern provenances are on the contrary with nearly 100% of crooked trunk, long and pendent lateral branches, which results in low percentage of wood yield and low value of usage.

Size of Leaves

Ecology has revealed the strong adaptability of size and structure of leaves in the life of forest trees. Measurements made in many plantations indicated that remarkable differences in the size of leaves existed among provenances. The F-value of the mean leaf-area measured in the 48 provenances in the plantation at Beijing was 29.0**, ranging from 2.6 cm^2 to 7.6 cm^2. The results measured in the 40 provenances in plantation at Lan Chow showed that the maximum leaf area was 7.8 cm^2 and the minimum only 2.0 cm^2, differing by four times. The leaf area of the southern provenances was generally larger than that of the northern arid area.

Moisture contents of the leaves were measured many times in consecutive years. The results show that although there were obvious differences among provenances, no geographical trend was apparent and it is evident that this character was controlled by more complex biological processes.

Moisture Content of the Twigs and Roots

In order to examine the reason for the difference in shoot-tip dieback among provenances through winter, studies on the moisture content of the twigs collected from 5-year-old juvenile trees in early, mid and late winter, and of the above ground part as well as the underground part of 1-year-old seedlings were carried out. The method was to collect 1-year-old twigs of 0.3 cm to 0.5 cm in diameter from 10 trees in each provenance, then put in a green house for air-drying and weighing every day. Finally the moisture content percentage (the mean value in the three periods) of the twigs from the different provenances was calculated after the oven-dry twig was weighed. Results showed that there are significant differences in the moisture content among provenances ($F = 3.4$, $P < 0.05$) with the extreme value ranging from 60.9% to 73.1% (dry weight). The moisture content was an adaptive feature because the moisture content of the twigs of the northern provenances in winter was generally higher than that of the southern provenances.

The moisture content of the above ground part and the underground part of the 1-year-old seedlings planted in pots from 20 seed sources was calculated in 1979 and it was found that the moisture content of the aboveground part of the southern origins averaged 45% and that of the northern provenances was around 55% in average. These were similar to the results obtained with the 5-year-old trees in plantation at Beijing. It can also be seen from the calculation that the moisture content of roots (averaged 55% for all provenances) was higher than that of stem but the moisture content of roots among the southern and northern origins had no differences.

The moisture content of the twigs during the winter influenced the shoot dieback in various of the provenances. The correlation coefficient between the dieback indexes of the different provenances measured at Chinghai plantation where the dieback was the most serious after winter and the moisture content of the twigs measured in Beijing was $r = -0.4834$**, which showed that the ability of cold-resistance could be forecasted by determining the twig moisture content.

Winter-Injury

White elm is a tree species which stops growing very late at different sites and still grows slowly till the time of early frosts. Thus, its top is not lignified in autumn and dieback happens after winter. This phenomenon widely exists in the various plantations. But as the ceasing time of growth of White elm differs among provenances, so the dieback indexes of the shoots after winter are different. The Sining plantation established at the elevation of 2230 m shows the clearest difference among provenances. For example, the correlation coefficient between frost-indexes of the 2-year-old seedlings and physiological latitude of the seed sources (geographical latitude + elevation conversion) was $r = -0.62$** and longitude $r = 0.48$**, annual mean temperature being $r = 0.60$**, extreme lowest temperature being 0.50**, and frost-free period being 0.64**. The dieback indexes of the northwestern inland provenances through winter was 0%, while those of the provenances from the Yellow River - Huaihe River valley exceed 70%. The linear regression equation of frost-injury index and latitude of origin was $y = -2.66 + 118.56X$ (the standard deviation of expected value and observed value $S = 15.12$), which means that corresponding to the increase of latitude by one degree, the decrease of dieback index is 2.66%.

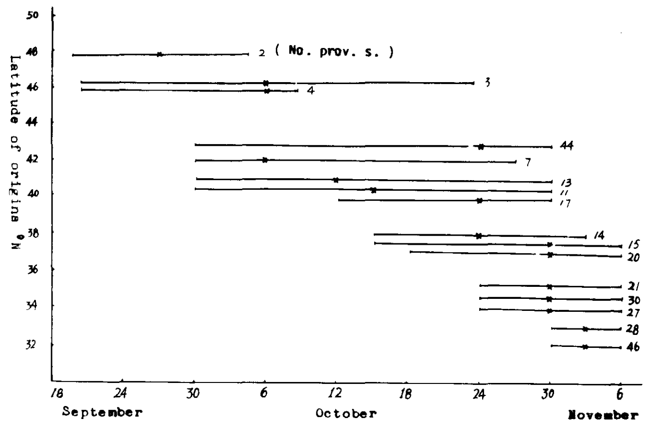
Cessation of Height Growth

Since the differences of flushing among provenances in spring are minor, we mainly introduce the differences of provenances in cessation of height growth.

According to the observations (once every two days) on the cessation of height growth of the 1-year-old seedlings in 20 seed sources in 1979, the general tendency was that the seedlings originating from the northern portion of the range ceased their height growth from the end of September to the first of October, while the seedlings originating from the central part of the range ceased their height growth from the second ten days of October and the seedlings originating from the southern part of range began ceasing their height growth in the first ten days of November. A few of the seedlings from the most southern portion did not cease height growth at all so that they suffered frost-injury in autumn. Cessation of height growth was closely correlated with geographical latitudes of the origins with $r = 0.9236$**.

Figure 3 illustrates the process of cessation of height growth of 20 seed sources collected throughout the range in China. It shows that the further north the origin, the earlier is the cessation of height growth, and the further south the origin, the later is the cessation of height growth.

In addition, the duration of cessation of height growth between northern and southern seed sources was apparently different. For example, in our experiment the



× Bud-set data of 50% individuals of observed seedlings

Figure 3. — Process of bud-set of 16 seedlots collected from different regions in China.

budding process from the earliest to latest one among different individuals ranged from 7 days to 14 days within southern populations, and within northern populations this process extend more than 20 days to 30 days.

Duration of Dormancy

In the winter 1984 to 1985, from November 15 to mid March of the following year, using the 48 seed sources in the plantation at Beijing as experimental materials, one branch about 50 cm in length was collected randomly from each of the ten 5-year-old trees in each seed source monthly and they were at once plunged in pots with tap water which were put in a greenhouse of 10° C to 20° C and the photoperiod was natural without altificial supplement. The date of bud-flushing was recorded daily. By the end of the experiment, three data of budding within provenance were calculated for each of all the seed sources. First, the interval between the collecting and earliest bud-bursting of any one of the ten branches in each seed source. Second, the interval between the collecting and bud-burst of 50% of the ten branches in each seed source. Third, the interval between the earliest and the latest bud-burst of the ten branches in each seed sources.

The results showed that in the first time of collection, namely on November 15, 1984, the above defined three portions of time had the most significant differences among the seed sources. As the time of collection went on, these differences gradually decreased, and the time between the earliest and the latest budburst within the seed source sharply reduced.

The differences in date of budding among the origins indicated the difference in duration of dormancy of each of all the origins. The data showed that the time of the first budding among different origins ranged from 18 days to 33 days and the time for 50% budding varied 26.8 days to 41.0 days. The general trend is that the seed sources from the northern part of the range removed from dormancy earlier than those from the southern part of the range, i.e. the southern populations were characterized by longer dormancy. This is in line with the behavior of most temperate tree species. The calculations showed that the northern populations finished their dormancy by the end of December but the southern populations ended their domancy by the middle of January. Duration of dormancy of White elm showed a latitudinal cline similar to its height growth, size of leaves etc. and this is a physiologically adaptative reaction to environment of their habitat.

The Geographical Variation Trend of the Major Characteristics

In order to reveal the geographical variation patterns of the major characteristics of White elm (growth, quality and adaptability), we carried out correlative analysis between characteristics and the geographical variables of all provenances, and the major meteorological factors of origin. The results are shown in *Table 6*. As there are so many experimental plantations, only the date of experimental plantations in ecologically representative areas are listed in the table.

The data in *Table 6* indicated that many characters of White elm showed clinal patterns with the changes of

Table 6. — Correlation coefficient between the major characteristics and geographical variable of origins (r).

Characteristics	Factors / Plantations	Latitude	Longitude	Elevation
Height growth of the trees	Hu Tor Bi, Sinkiang	−0.5059**	0.7546	−0.6195**
	Lan Chow Municipality, Kansu	−0.680**	0.217	−0.310
	Yan Chow County, Shantung	−0.5253**	0.7546**	−0.6195**
	Beijing Municipality	−0.5615**	0.2510	−0.423**
	Xing Cheng County, Liaoning	−0.3592**	0.5013	−0.5464**
	Hu He How Te Municipality, Inner Mongolia	−0.5352**	0.3173	−0.3760**
Adaptable characteristics	1. Leaf area			
	Beijing Municipality	−0.2380	0.2693*	−0.4863**
	Lan Chow Municipality, Kansu	−0.464**	0.398**	−0.477**
	2. Dieback index			
	Xi Ning Municipality, Chinghai Province	−0.6395**	0.2692	−0.2433
	Hu He How Te Municipality, Inner Mongolia	−0.5522**	0.1189	−0.0612
	3. Duration of height growing			
	Beijing Municipality	−0.7728**	0.2796	−0.038
	Hu He How Te Municipality, Inner Mongolia	−0.6053**	0.3953*	−0.4453**
	Lan Chow Municipality, Kansu	−0.375*	0.307*	−0.533**
	4. Moisture content of twigs			
	Beijing Municipality	0.5135**	0.0482	−0.1474*
Ratio of crooked trunk	Beijing Municipality	0.6399**	−0.1342	0.3670**
	Xing Cheng County, Liaoning Province	0.5832**	−0.4441**	0.4104**
	Hu Tou Bi County, Sinkiang	0.6436**	−0.0771	0.3325**

Table 7. — The partial correlation coefficient between characters and geographical variables oi origins.

Characteristics	$r_{y\ 3.12}$	$r_{y\ 2.13}$	$r_{y\ 1.23}$	Coefficient of complex correlation (r)
Tree height	0.7266	0.1740^{NS}	−0.5230	0.7826
DBH	−0.6841	-0.1502^{NS}	−0.4964	0.7493
Duration of dormancy	−0.4634	0.0471^{NS}	-0.2785^{NS}	0.5039
Moisture content of twigs	0.5720	0.0954^{NS}	0.2924^{NS}	0.5986
Ratio of defoliated plants (23. November)	0.9236	0.2447^{NS}	0.6938	0.9309
Leaf area	−0.3972	0.0488^{NS}	−0.4723	0.5975
Ratio of crooked plants	0.7930	0.0053^{NS}	0.5802	0.8250
Width of crown	0.6961	0.1576^{NS}	0.4590	0.7467

Note: NS stands for not significant. Those without NS mean a highly significant correlation.
1, 2, and 3 represent latitude, longitude, and elevation, respectively.

Table 8. — The correlation coefficient between the major factors and the ecological geographical variables of seed sources.

Factors	Longitude	Elevation	Annual mean temperature	Extreme lowest temperature	Annual rainfall	Duration of frost-free season
Latitude	0.1720	−0.1940	−0.7296**	−0.8670**	−0.5312**	−0.7633**
Longitude	1.00	−0.5503**	−0.1018	0.1092	0.4430**	0.521
Elevation		1.00	−0.3910**	−0.1291	−0.3154**	−0.3445**
Annual mean temperature			1.00	0.7900**	0.5393**	0.8607
Extreme lowest temperature				1.00	0.611**	0.7832**
Annual rainfall					1.00	0.5959**

* significant at the 5 percent level
** significant at the 1 percent level

latitude and elevation, and only few characteristics changed with the difference of longitude. Because the different locations at the same latitude in our country have great differences in longitude and elevation, the simple correlation obtained between characters of White elm and geographical variables of each origin could not fully reveal the essence of this relationship. Therefore, calculations of the partial correlation coefficient between characters latitude, longitude and elevation of the 48 seed sources was also conducted, the results are listed in *Table 7*.

The correlation coefficients in *Table 7* clearly indicated that most of the characters were strongly correlated with latitude and were moderately correlated with elevation but basically had no correlation with longitude. Consequently, it can be suggested that latitudinal cline is the major pattern of genetic variation of White elm. This variation pattern, actually, reflects the adaptation of the different seed sources to the dry-moisture, cold-warm, day-length and the sun-light quality. Since the geographical coordinate of a location generally shows the comprehensive type of the local meteorological elements, the correlation between geographical and ecological elements of the 48 seed sources and the results are given in *Table 8*.

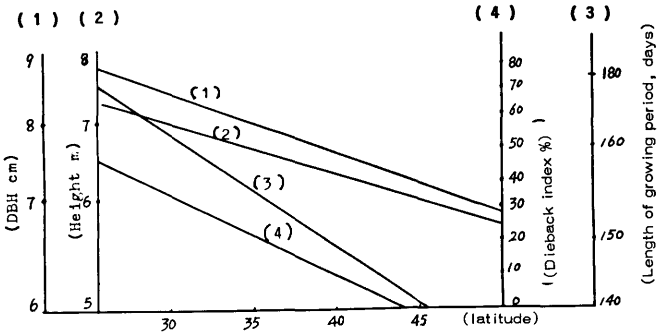


Figure 4. — Regressive relationship between the characters of White elm and the latitude of origins.

The data in *Table 8* revealed that role of latitude in geographical variation was stronger than that of longitude for the fact that it had strongly significant correlation with the major meteorological variables such as light, warmth, rainfall and others, so that it is an important representative of origins' variables. Elevation played a moderate role in the geographical variation because it had a greater representative of ecological factors than longitude. Therefore, the moisture and warmth were the dominant factors of the natural selection of genetic variations of White elm.

The extent of genetic differentiation of the major characteristics of White elm due to the difference of latitude is an important basis to estimate the degree of geographical difference of the various seed sources as well as a basis for seed allocation and transfer to various regions in a planned way. *Figure 4* shows the linear regression diagram and their tendency of the major characteristics with latitude and the behavior of plants of White elm from different locations.

Geographical Regions

According to the cluster analysis and principal component analysis on the 7 factors including height, DBH, ratio of the length of lateral branches and tree height, leaf area, percentage of crooked plants, percentage of bud-burrsting individuals on 5 April, percentage of defoliated plants on 23 November obtained from the 4-year-old plantation at Beijing, the 48 seed sources were divided into three geographical groups according to discrete sets in the diagram of two-dimensional coordinates of the principal component analysis (*Fig. 5*). The first group (I) includes Kiangsu, Anhwei, Hupei, Honan, the central southern

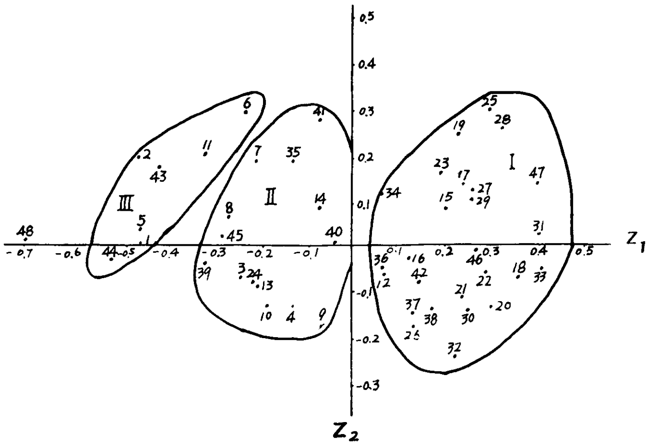


Figure 5. — The arrangement of two-dimensional coordinate of PCA of seed sources (Beijing plantation.)

Hopei, the central southern Shensi and the lower reach of Fenhe river in the south part of Shansi province. The third group (III) includes Heilungkiang, Kirin provinces, the north of Liaoning prorince, Inner Mongolian Autonomous Region and the entire Sinkiang Uighur Autonomous Region. The second group (II) locating between the above two groups, includes the south part of Liaoning province, the north of Hopei province, the most part of Shansi, the central northern Shensi, the eastern Kansu, the Yellow River basin in the east of Ninghsia and Chinghai Province, Tibet can be regarded as an independent group because plants from this region behaved differently and the locus in the diagram was located very far from all others.

As most of the characters of White elm showed a clinal pattern from the southeast toward the northwest so the division of the geographical groups is conditional and the demarcation lines of geographic groups are not absolute. They were drawn in view of the landforms and relief as well as the climatic peculiarity of the natural range of White elm. Actually, the boundary is not a line but a band. For example, the first geographical group has plain landform and the climate of subtropic — warm temperate zone. The third geographic group consistes of stepped gobi and oasis belonging to desert-steppe climate. The second geographical group embodies the landforms of mountains and loess plateaus in the north central China with a transitional climate between the previous two geographical groups. Because of evolutionary response to environmental factors varying gradually with latitude, the obvious difference in morphological and ecological characteristics only exists among populations inhabited at both the extreme portions of range of White elm, and the difference between the adjacent populations generally was not visible. For this reason, generally speaking, the provenances in the first geographical group are fast growing with straight stems, slender crowns, larger leaves, relatively, little developed root systems and low hardiness which are late in flushing and cessation of annual height growth. The provenances in the third geographical group are slow growing with a majority of crooked stems, well developed lateral branches, smaller leaves, early bursting, early ceasing of annual height growth, well developed root systems and high hardiness. The provenances of the second group exhibit transitionary status in their morphological, phenological and physiological characters.

Conclusions

1. The growth ability, stem, phenological phases, size of leaves of White elm shows a clinal pattern of latitudinal variation.
2. The geographical variation of the characteristics of White elm have strict ecologically adaptable meaning and are an adaptive response to the local natural selection pressure.
3. The lower Yellow river valley in China is an area concentrating superior genes of White elm trees whose progeny is a superior gene resource for breeding of fast-growing varieties with good form.

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