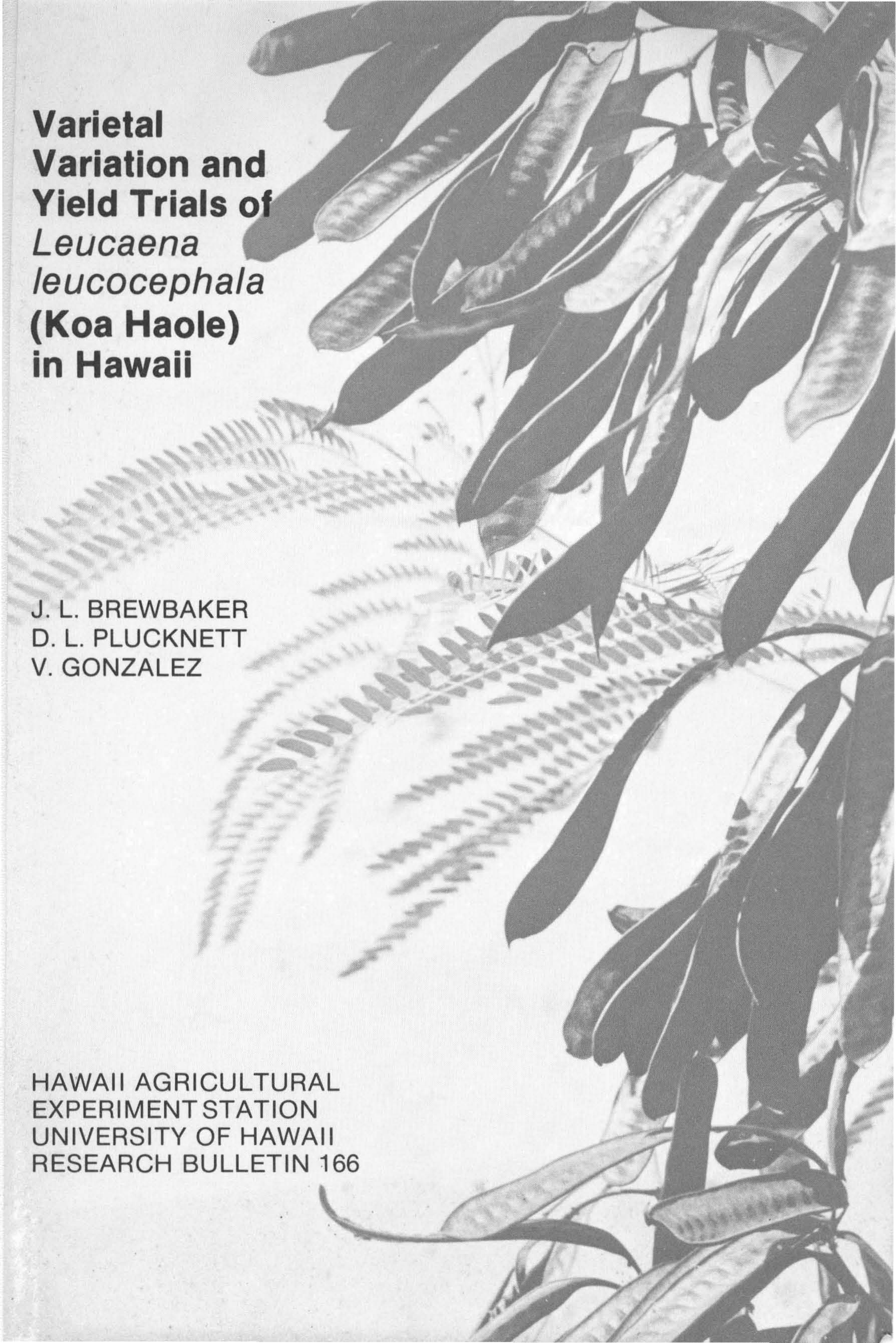

Varietal Variation and Yield Trials of *Leucaena leucocephala* (Koa Haole) in Hawaii

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VARIETAL VARIATION AND YIELD TRIALS OF *Leucaena leucocephala* (KOA HAOLE) IN HAWAII

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Leucaena leucocephala (Lam.) de Wit is a pantropical leguminous shrub known as "koa haole" in Hawaii. It is used widely throughout the world for forage and food, and is one of the highest yielding, high-quality legumes of the tropics (Dijkman, 1950; Oakes, 1968). A major recent review of the botany and of agricultural uses of this plant has been made by Oakes (1968).

In the belief that koa haole's potentiality as a source of human and animal protein in the tropics can be realized only through plant exploration and breeding, a world collection of *Leucaena* germplasm has been assembled at the Hawaii Agricultural Experiment Station. The following is a report of this collection and of yield trials which have identified outstanding strains in it.

Leucaena leucocephala (formerly referred to as "*L. glauca*") originated in Central America. An aggressive strain of this species spread through the tropics from ports on the west coast of Mexico, where it still may be seen today. Its introduction into Hawaii is surmised to have occurred around 1860, and it evidently spread rapidly throughout the Islands.

This shrubby strain of *Leucaena* is typical of most koa haoles outside the North American continent, and has been called the "Hawaiian type." The extensive *Leucaena* research conducted in Hawaii has been confined largely to this strain. The fact that the Hawaiian-type koa haole is a highly aggressive weedy shrub throughout the tropics may encourage the view that the best yielding strains would be those derived from this strain. However, the following study identifies the Hawaiian type of koa haole as one of the poorest strains in yield trials.

MATERIALS AND METHODS

Between 1963 and 1968, there were 104 strains of *Leucaena* studied in an observational nursery at the Waimanalo Experimental Farm. Most accessions were from countries in which the species was widely naturalized but not native. The materials and methods for each of the experiments are described in detail in the Appendix.

RESULTS AND DISCUSSION

Species and Varietal Variation in *Leucaena*

Fifty-one species have been reported in the genus *Leucaena* Benth., family Mimosaceae (Table 1). Many of these designations are synonymous, and only 10 species appear to be of unquestioned validity. Collections have been made *in situ* of all 10 of these species by the senior author.

Leaves, pods, and young seeds of at least 4 *Leucaena* species have been used as human food since the time of the Mayans. They appear to have constituted a significant protein supplement in several areas of Southeast Asia and Central America. *Leucaena* species are used in erosion control, and as shade trees, windbreaks, and sources of fence posts and charcoal. *L. leucocephala* is the only species used as a forage crop. The high intercross fertility of this and other species (Gonzalez, Brewbaker, and Hamill, 1967) suggests that improvement of *L. leucocephala* as a forage, forest, or human food crop may assume many directions.

Varietal variation in *L. leucocephala* is comparatively limited among those accessions which have been tested. This variation is restricted principally to 2 types—the Hawaiian and the "Sal-

Table 1. Species of the mimosaceous genus, *Leucaena* Benth., and synonymies evident in 1967 explorations sponsored by the New Crops Research Branch, United States Department of Agriculture

Species epithet		Type locale*	Visited**	Synonymy if any
1. Species of apparent taxonomic validity:				
L. collinsii Britton & Rose	1928	Chiapas	Yes	
L. diversifolia (Schlecht) Benth.	1842	Vera Cruz	Yes	
L. esculenta (Moc. & Sesse) Benth.	1875	"New Spain"	Yes	
L. lanceolata Watson	1886	Chihuahua	No	
L. leucocephala (Lam.) de Wit	1783	"America"	Yes	
L. macrophylla Benth.	1844	Guerrero	No	
L. pulverulenta (Schlecht) Benth.	1842	Vera Cruz	Yes	
L. retusa Benth.	1852	Texas, United States	No	
L. shannoni Donn. Smith	1914	Salvador	Yes	
L. trichodes Benth.	1842	South America	No	
2. Species of apparent synonymy to those listed in (1) above:				
L. blancii Goyena	1909	Nicaragua	No	*L. leucocephala*
L. bolivarensis Britton & Killip	1936	Colombia	Yes	*L. trichodes*
L. boliviana Rusby	1912	(No information)	—	—
L. brachycarpa Urban	1900	Jamaica; Vera Cruz	Yes	*L. diversifolia*
L. brandegeei Britton & Rose	1928	Baja California	No	*L. macrophylla*
L. canescens Benth.	1843	Ecuador	No	*L. trichodes*

Table 1. Species of the mimosaceous genus, *Leucaena* Benth., and synonymies evident in 1967 explorations sponsored by the New Crops Research Branch, United States Department of Agriculture —Continued

Species epithet		Type locale*	Visited**	Synonymy if any
L. colombiana Britton & Killip	1936	Colombia	Yes	*L. trichodes*
L. confusa Britton & Rose	1928	Jalisco	Yes	*L. esculenta*
L. cruziana Britton & Rose	1928	Vera Cruz	Yes	*L. lanceolata*
L. cuspidata Standley	1919	San Luis Potosi	No	*L. lanceolata*
L. doylei Britton & Rose	1928	Chiapas	Yes	*L. collinsii*
L. dugesiana Britton & Rose	1928	Guanajuato	Yes	*L. diversifolia*
L. glabrata Rose	1897	Guerrero	No	*L. leucocephala*
L. greggii Watson	1888	Nuevo Leon	No	*L. leucocephala*
L. guatemalensis Britton & Rose	1928	Guatemala	Yes	*L. diversifolia*
L. houghii Britton & Rose	1928	Morelos	Yes	*L. macrophylla*
L. laxifolia Urban	1900	Vera Cruz	Yes	*L. diversifolia*
L. macrocarpa Rose	1895	Jalisco	Yes	*L. macrophylla*
L. microcarpa Rose	1897	Baja California	No	*L. macrophylla*
L. molinae Standley	1950(?)	Honduras	Yes	*L. diversifolia*
L. multicapitula Schery	1950	Panama	Yes	*L. trichodes*
L. nelsonii Britton & Rose	1928	Guerrero	No	*L. macrophylla*
L. nitens Jones	1929	Sinaloa	Yes	*L. lanceolata*
L. oaxacana Britton & Rose	1928	Oaxaca	Yes	*L. diversifolia*
L. pallida Britton & Rose	1928	Jalisco	No	*L. diversifolia*
L. palmeri Britton & Rose	1928	Sonora	No	*L. lanceolata*
L. paniculata Britton & Rose	1928	Morelos	Yes	*L. diversifolia*
L. plurijuga Standley	1919	Michoacan	Yes	*Albizzia plurijuga*
L. pseudotrichoides Britton & Rose	1928	Nicaragua	No	*L. trichodes*
L. pubescens Britton & Rose	1928	Sinaloa	Yes	*L. lanceolata*
L. pueblana Britton & Rose	1928	Oaxaca	Yes	*L. diversifolia*
L. purpusii Britton & Rose	1928	Vera Cruz	Yes	*L. lanceolata*
L. rekoi Britton & Rose	1928	Oaxaca	Yes	*L. macrophylla*
L. revoluta Britton & Rose	1928	Chiapas	Yes	*L. diversifolia*
L. salvadorensis Standley	1928	Salvador	Yes	*L. leucocephala*
L. sinaloensis Britton & Rose	1928	Sinaloa	Yes	*L. lanceolata*
L. sonorensis Britton & Rose	1928	Sonora	No	*L. lanceolata*
L. standleyi Britton & Rose	1928	Salvador	Yes	*L. diversifolia*
L. stenocarpa Urban	1900	Oaxaca	Yes	*L. diversifolia*
L. trichandra(Zucc.) Urban	1900	Munich Bot. Gdn.	No	*L. diversifolia*
L. ulei Harms	1907	(No information)	—	*L. diversifolia*

3. Taxa with no apparent taxonomic validity: "L. buitenzorg" (=*L. diversifolia*), "*L. cookii*"

*States in Mexico and other locations.

**"Yes" indicates that the type locality was visited by senior author on 1967 plant exploration sponsored by New Crops Research Branch, U.S. Department of Agriculture.

vador" types (Figure 1). About 80 percent of the 330 accessions collected from more than 40 nations where this species is now widely naturalized (e.g., Philippines, Indonesia, Taiwan) have proved to be of the Hawaiian type. This type is a drought-tolerant, highly branched, abundantly flowering, and aggressively weedy shrub growing to 30 feet. A detailed description of variation in 104 *Leucaena* accessions grown in Hawaii is given in the Appendix, Experiment 1.

The Salvador type (designated "*L. salvadorensis*" by some authors, with no obvious justification) was selected originally as a shade and windbreak tree for coffee and other crops. In contrast to the Hawaiian type, it is usually erect and may attain a height of 60 feet, producing large leaves, leaflets, pods, and seeds (Figure 1*b*, 1*c*). It flowers sporadically and seasonally, as do most other species of *Leucaena*. Its spring- and autumn-flowering habit allows the Salvador type extended vegetative periods, and it has out yielded the Hawaiian type in comparative forage trials in Australia (Hutton and Bonner, 1960) and the Caribbean Islands (Oakes and Skov, 1967).

L. leucocephala has the greatest geographical distribution of all the 51 species. In phenotypic variability, however, the species *L. diversifolia* appears to exceed that of all other species. Fourteen species were concluded to be synonymous with *L. diversifolia* (Table 1). Chromosome counts revealed this to be a diploid species ($2n=52$) with a seed enzyme spectrum very distinct from other 52-chromosome species, *L. lanceolata* and *L. trichodes*, as well as from the 56-chromosome *L. pulverulenta* and the 104-chromosome *L. leucocephala* (Brewbaker, J. L., unpublished data). Field studies in Guatemala and southern Mexico appear to warrant the suggestion that *L. leucocephala* originated as an allotetraploid hybrid of *L. diversifolia* and *L. collinsii*. The 2 major types of *L. leucocephala* (Hawaiian and Salvador) may thus be viewed as northern and southern strains of this species. The Hawaiian type traces clearly back through western Mexican ports to the Yucatan peninsula.

Gray (1967*a*, *b*, *c*) made genetic studies of stem lengths and branching patterns in 5 varieties of *L. leucocephala* and their progenies. The following strains were studied:

Source	*C.S.I.R.O. C.I. Number*[1]	*USDA P.I. Number*[1]	*Type*
Hawaii	18624	288000	Shrubby, early flowering, Hawaiian
Bald Hills, Australia	—	282469	Shrubby, early flowering, "
Guatemala	18228	284758	Erect, late flowering, Salvador
Salvador	18623	281770	Erect, late flowering, "
Peru	18614	280122	Semi-erect, late flowering, Peru

[1]C.I. (Australia) and P.I. (United States) numbers are federal plant introduction numbers that permanently identify all accessions.

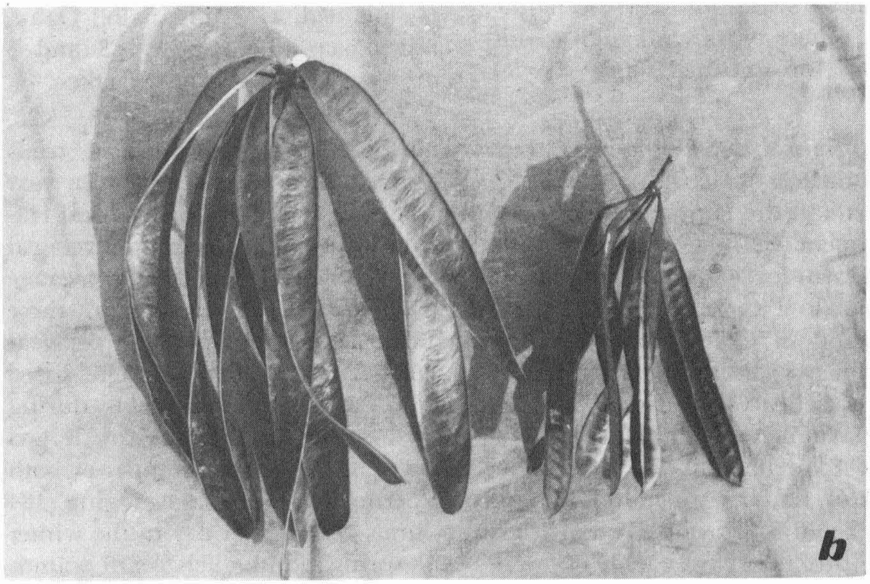

Figure 1. *Leucaena leucocephala* Salvador-type strain K8 (on left) and Hawaiian-type strain K63 (on right); *(a)* trees in 2-year-old windbreak planting; *(b)* mature seed pods; *(c)* mature leaves, pods, and seeds.

The erect habit of Salvador types was inherited as a monogenic trait, with complete dominance of the erect habit, in Gray's studies. Crosses made in Hawaii, however, stress the multigenic basis for vigor that accompanies these habit variations. Flowering dates were observed by Gray to be inherited independently of erect habit, as were branching habits. Estimates of general and specific combining ability from diallel analyses suggested a high additivity and limited heterotic or nonadditive component associated with stem length values. The principal Australian selections have been low, dense forage types with high yields, suitable for grazing (Gray, 1967*a*).

Yield Trials of Koa Haole in Hawaii

Among 330 varieties or species of *Leucaena* in the Hawaii Agricultural Experiment Station collection, 104 were grown for a year or more at the Waimanalo Experimental Farm, on the Island of Oahu (*see* Appendix, Experiment 1). Preliminary yield trials of 70 varieties were planted in 1964 at the Waimanalo Farm and at the Kapaa Experimental Farm, on the Island of Kauai (Appendix, Experiments 2 and 3). Advanced yield trials of 22 outstanding varieties were planted in 1966 and 1967 at these two locations and also on Maui (Appendix, Experiments 4, 5, and 6). The conclusions drawn from these trials are summarized briefly here, and then described in detail in the Appendix.

The best yielding koa haoles were Salvador type varieties of *L. leucocephala*. Other species and strains were slower growing and low in yields, although some are of probable value in plant breeding for low mimosine content, cold tolerance, etc.

Yield rankings of 70 varieties in the preliminary trials (3 replications and 2 cuttings at Waimanalo, 1 replication and 2 cuttings at Kapaa) were very similar (Appendix, Experiments 2 and 3), and 22 of the 70 varieties were chosen for replicated trials, with the local Hawaiian variety as check. Advanced yield trials included the 22 varieties in an augmented block experiment, with about half the entries replicated 4 times. The experiment was planted at Waimanalo, Oahu, and Kapaa, Kauai, where 3 and 5 cuttings, respectively, were taken.

The leading varieties (K8, K28, and K67) in these replicated trials averaged 42 tons per acre per year green weight (Table 2). The local Hawaiian check, in contrast, averaged only 17 tons. The composite average of all replicated varieties in these trials was 28.9 tons per acre per year (yield values in Table 2 were based on average daily increments during the 8 cutting periods). Growth was slower in the winter months at both Experimental Farms, averaging 184 pounds per acre per day in the winter and spring months, versus 278 pounds per acre per day in the summer and autumn months for the 3 leading varieties. These seasonal differences appeared much smaller in a dry, sunny experimental area on Maui provided by the Soil Conservation Service for their cooperative trial (Appendix, Experiment 6; Lewis and Palmer, 1968). Neither the Waimanalo nor the Kapaa Farm represents the leeward

Table 2. Yields of koa haole from 11 varieties in replicated advanced yield trials, 1965–1967

Location	Cutting no.	Season	Days to cutting	Forage yields in pounds/acre/day: Hawaiian check	Average all varieties	Average top 3 varieties*
Kapaa, Kauai	1	Summer	115	111.7	175.7	275.9
	2	Fall	97	89.1	165.6	262.8
	3	Winter	115	55.6	109.2	163.2
	4	Spring	137	64.6	121.2	175.0
	5	Summer	128	94.3	188.4	280.3
Waimanalo, Oahu	1	Winter	94	94.6	135.4	185.6
	2	Spring	92	101.9	155.4	212.2
	3	Summer	53	146.7	214.1	294.5
Average in pounds/acre/day				94.81	158.13	231.19
Average in tons fresh/acre/year				17.3tons/acre	28.9tons/acre	42.2tons/acre
Average in tons dry**/acre/year				5.5tons/acre	9.2tons/acre	13.4tons/acre

*Top 3 varieties = K8, K28, and K67.
**12% moisture assumed.

lowlands of Hawaii, in which koa haole yields should maximize at well over 50 tons per acre per year for varieties presently available.

The following are among conclusions drawn from these yield trials:

1. Superior varieties K8, K28, and K67 averaged 42 tons of green forage per acre per year, or 13.4 tons of hay (12 percent moisture); dry weights averaged 28 percent, with 80 percent green vegetative matter on the 3-month-cutting regime.
2. These superior varieties yielded two and a half times as much forage as the Hawaiian variety.
3. Superior varieties were of the Salvador type, seasonal-flowering trees (to 60 feet) with large leaves, fruits, and seeds, and moderate mimosine content (4.5 percent dry weight).

The 3 varieties which emerged as superior are difficult to distinguish phenotypically. K8 seeds (PI 263695) were received as "*L. esculenta*" from Zacatecas (Guerrero), Mexico, but proved to be a variety of *L. leucocephala*. K28 (PI 281607) was obtained from the state of Yucatan, Mexico, and K67 (PI 288005) from plants tracing to a selection on the Santa Cruz Porillo Agricultural Experiment Station, in El Salvador. Large populations of these strains have been planted for selection and seed increase.

It is doubtful that protein can be grown much more efficiently or economically in the lowland tropics than it can from pure stands of *L. leucocephala* harvested regularly as hay or forage. Total protein yields in irrigated, well-managed plantings of superior varieties can be projected to exceed 3 tons per acre per year. In the present trials, total protein yields of 4320 pounds per acre per year were calculated for the 3 leading varieties. These values were computed from the dry matter yields of 10.8 tons and the average values of 80 percent vegetative matter and 25 percent protein. Protein values were computed by Gonzalez (1966) from micro-Kjeldahl determinations on the edible portion of 20 varieties in this trial: these values, based on total protein nitrogen, were corrected for mimosine nitrogen. These high protein values for *Leucaena* confirm previous reports summarized by Oakes (1968) and Gray (1968).

Mimosine levels in the superior yielding varieties were as high as in the Hawaiian type (Table 3). Only the Colombian varieties and related species (e.g., *L. pulverulenta*) proved significantly low in mimosine contents. The toxic effects of mimosine (reviewed by Oakes, 1968) must be considered in the feeding of koa haole, especially to nonruminant animals. The nutritional competence of koa haole as a source of carotene and vitamins A and K has been emphasized in many studies (Chou and Ross, 1965; Oakes, 1968).

Management Considerations for Salvador-Type Strains

Agronomic studies of koa haole have been conducted largely with the poor yielding Hawaiian type (Takahashi and Ripperton, 1949; Kinch and Ripperton, 1962; Oakes and Skov, 1967; Hutton and Bonner,1960). The Salvador types recommended here have a rapid, erect growth and become excessively woody unless harvested regularly. Management and yield maximization studies with and without companion grasses are needed on these types. Plant populations in the trials reported here were evidently too low (about 20,000 plants per acre). Populations up to at least 80,000 plants per acre (about 10 pounds of seed) deserve study. Forage yields may not be influenced greatly by plant population, but an increase in stand should reduce woodiness and crown size and help control weeds.

Erect strains must be harvested more frequently than shrubby strains. While the average frequency of cuttings in these trials was 3½ per year, the per-day yields maximized for the shortest cutting period of 53 days (Table 2), and this harvest was notably less woody. Where moisture is not limiting in warmer lowland areas, an 8-week cutting period, or about 6 cuttings per year, is recommended.

Little is known of the soil fertility practices that would maximize koa haole yields from long-term cropping, but it is obvious that phosphate and potash deficiencies would develop and need correction if, for example, yields of 50 tons per acre per year are to be maintained. Soil pH levels should be neutral or alkaline for best koa haole growth (Takahashi and Ripperton, 1949). Soil incorporation of phosphate fertilizers might prove beneficial to good root development. In studies of root development in aluminous soils, Plucknett, Moomaw, and Lamoureux (1963) found that

Table 3. Observational nursery data on 104 *Leucaena* strains grown in Hawaii, 1964–68, with Plant Introduction numbers of the New Crops Research Branch, United States Department of Agriculture

USDA Plant Introduction no.	Hawaii no.	Origin	Erect (E), Suberect (S-E), or Shrub (S)	Average height in feet, 6 months	Flowering**	Mimosine mg/g dry weight
188810	K21	Philippines	S	3.5	5	35.8
237147	K110	Costa Rica	S	3.5	5	—
241167	K22	Philippines	S	6.0	3	48.1
247682	K23	Belgian Congo	S	3.5	4	47.7
*247683	K14	" "	E	8.0	1	25.5
263695	K8	Mexico	E	13.5	1	43.2
274470	K24	Union of South Africa	S	3.5	5	41.2
279180	K25	India	S	3.0	5	37.3
279577	K76	Taiwan	S	4.0	5	—
280122	K5	Australia (18614; ex. Peru)	S	7.5	4	32.8
281605	K26	Virgin Islands	S	3.5	5	43.8
281606	K27	Colombia	S	3.0	3	23.2
281607	K28	El Salvador	E	10.5	2	47.2
281608	K29	Honduras	E	14.0	1	41.5
281609	K30	Mexico (Yucatan)	S	5.0	3	46.5
281627	K31	Australia	S	3.0	5	34.4
281636	K32	Tanzania	S	4.5	5	34.9
281766	K15	New Guinea (4385)	S	7.5	2	37.8
*281767	K16	" " (4499)	S	5.5	3	35.9
*281768	K17	" " (4500)	S	6.0	2	36.6
*281769	K18	New Britain	S	5.0	4	34.9
281770	K1	New Guinea (4162; ex. Salvador)	E	12.0	2	33.2
281771	K3	" " (4163; ex. Guatemala)	S-E	10.0	3	33.0
281772	K6	" " (4164; ex. Peru)	S-E	8.5	3	35.4
281773	K33	" " (4498)	S-E	9.0	1	35.6
281774	K34	" "	S	5.0	4	34.4
281775	K35	New Britain	S	4.5	4	43.5
281777	K36	New Caledonia	S	3.5	5	39.8
281778	K37	" "	S	3.5	5	38.8
281779	K38	" "	S	3.5	5	36.9
281780	K39	Puerto Rico	S	4.0	5	37.3
281781	K40	Ceylon	S	4.0	5	48.9
281782	K41	Ghana	S	4.5	4	38.4
281783	K42	Sierra Leone	S	4.0	5	39.2
281784	K2	Senegal (ex. Salvador)	S	4.5	5	41.4
282396	K43	Philippines	S	4.0	5	41.1
282404	K44	Colombia	S	4.0	5	27.9

—Continued

Table 3. Observational nursery data on 104 *Leucaena* strains grown in Hawaii, 1964-68, with Plant Introduction numbers of the New Crops Research Branch, United States Department of Agriculture—Continued

USDA Plant Introduction no.	Hawaii no.	Origin	Erect (E), Suberect (S-E), or Shrub (S)	Average height in feet, 6 months	Flowering**	Mimosine mg/g dry weight
282405	K12	Honduras	S	6.0	2	41.2
282458	K45	Colombia	S	3.0	5	20.3
*282460	K9	Tonga	S	4.0	1	0.0
282461	K46	Australia	S	4.0	5	47.0
282462	K47	Fiji (19580; ex. Australia)	S	4.5	4	45.4
282463	K48	New Caledonia (19852; ex. Australia)	S	4.0	4	38.6
282464	K49	Brazil (28106; ex. Australia)	S	5.0	5	35.2
282465	K50	Philippines (29215; ex. Australia)	S	4.0	4	41.8
282466	K51	Thailand (29633; ex. Australia)	S	4.0	4	41.8
282467	K52	Vietnam (30479; ex. Australia)	S	4.5	4	36.2
282468	K53	Vietnam (30481; ex. Australia)	S	5.5	4	39.2
282469	K54	Australia (Bald Hills)	S	6.0	5	39.7
282470	K55	" (Darwin)	S	4.0	5	35.0
282471	K56	" (Gayudah)	S	4.0	5	28.5
282472	K57	" (Gympi)	S	5.0	4	37.8
282473	K58	" (Innesfail)	S	5.0	4	42.8
282474	K13	Taiwan (31182; ex. Australia)	S	4.0	5	38.1
282692	K59	Mexico (Vera Cruz)	S-E	8.0	3	35.2
282817	K60	Taiwan	S	5.0	4	41.4
283697	K61	New Caledonia	S	4.0	5	46.8
284758	K4	Australia (18228; ex. Guatemala)	E	11.5	2	29.4
*286223	K19	Texas, United States	S	7.0	1	18.9
*286248	K10	Mexico	S-E	9.0	1	37.6
286295	K62	Ivory Coast	S-E	9.0	1	38.6
*286296	K11	" "	S	7.0	1	21.2
288000	K63	Hawaii, United States	S	4.0	5	44.2
288001	K64	Uganda	S	5.0	3	45.4
288002	K7	Australia (ex. New Caledonia)	S	4.0	3	39.3
288003	K65	Mexico (Vera Cruz)	S	4.0	5	40.6
288004	K66	El Salvador	E	9.0	2	34.3
288005	K67	"	E	11.0	2	37.4
288006	K68	Philippines	S	4.0	5	35.2
288007	K69	Colombia	S	4.0	5	21.2
288008	K70	Singapore	S	5.0	3	32.8
288009	K71	Indonesia	S	6.5	2	39.6
*288010	K20	"	S-E	7.0	1	22.3

Table 3. Observational nursery data on 104 *Leucaena* strains grown in Hawaii, 1964-68, with Plant Introduction numbers of the New Crops Research Branch, United States Department of Agriculture—Continued

USDA Plant Introduction no.	Hawaii no.	Origin	Erect (E), Suberect (S-E), or Shrub (S)	Average height in feet, 6 months	Flowering**	Mimosine mg/g dry weight
288011	K72	Hawaii, United States (ex. Salvador)	S-E	8.5	3	43.2
290753	K73	Philippines	S	4.0	5	—
292345	K74	Bolivia (ex. Peru)	E	7.5	2	—
*294093	K75	Mexico	S-E	6.0	1	—
295360	K77	Taiwan	S-E	5.0	5	—
295361	K78	"	S	5.5	5	—
295362	K79	"	S	7.5	2	—
295363	K80	"	S	6.0	5	—
295364	K81	"	S	5.0	5	—
295365	K82	"	S	4.0	5	—
300010	K87	Union of South Africa	S	4.0	5	—
300011	K88	" "	S	5.0	5	—
304650	K99	Argentina	S	5.5	4	36.0
305453	K89	Sierra Leone	S	5.0	3	29.0
308544	K94	Colombia	S	5.0	3	19.3
308519	K95	Peru	S-E	6.0	3	37.6
308568	K96	Venezuela	S	6.0	5	40.0
311128	K97	Nicaragua	E	9.0	1	29.6
311513	K98	Brazil	S	4.0	5	32.9
312118	K101	Virgin Islands (18623; ex. Australia)	S-E	8.0	4	29.0
317908	K83	Indonesia	S	5.0	5	—
317909	K84	Fiji	S	4.0	5	—
317910	K85	American Samoa	S	5.0	5	—
317911	K86	Tahiti	S	6.0	5	—
317912	K91	Venezuela	S	6.0	3	37.6
317913	K92	Brazil	S	4.0	5	36.6
*317914	K90	Venezuela	S-E	3.0	1	36.2
*317915	K93	Guam	S	1.5	1	—
*317916	K103	(F_2 population of K19 X K63)	S-E	4.5	3	—
*317917	K107	Cameroun	S	3.5	1	—
317918	K108	Cameroun	S	3.0	5	—

*Species other than *L. leucocephala; L. pulverulenta* = 247683, 286223, 288010, and 294093; *L. leucocephala* x *L. pulverulenta* (or reciprocal, and advanced generations, thereof) = 281767, 281768, 281769, 317916; *L. diversifolia* = 286296 and 317917; *L. lanceolata* = 286248; *L. trichodes* = 317914; *Prosopis insularum* = 282460 and 317915.

**Flowering scored 1 (rare and seasonal) to 5 (abundant, regular).

phosphorus greatly stimulated root development and vigor of koa haole.

Although grown up to elevations of 5000 feet, as in New Guinea, koa haole is not a promising forage crop for cool tropical highlands, where its growth is very slow. Species like *L. pulverulenta*, however, resist frost and grow well in cool areas, encouraging interest in its hybrids with koa haole (Gonzalez, Brewbaker, and Hamill, 1967). These 80-chromosome hybrids were vigorous in growth, forming a 40-foot tree in 3 to 4 years (Figure 2). They were not heavily seedy, due to chromosomal sterility, and made an excellent windbreak on the Kapaa Farm at 600 feet elevation.

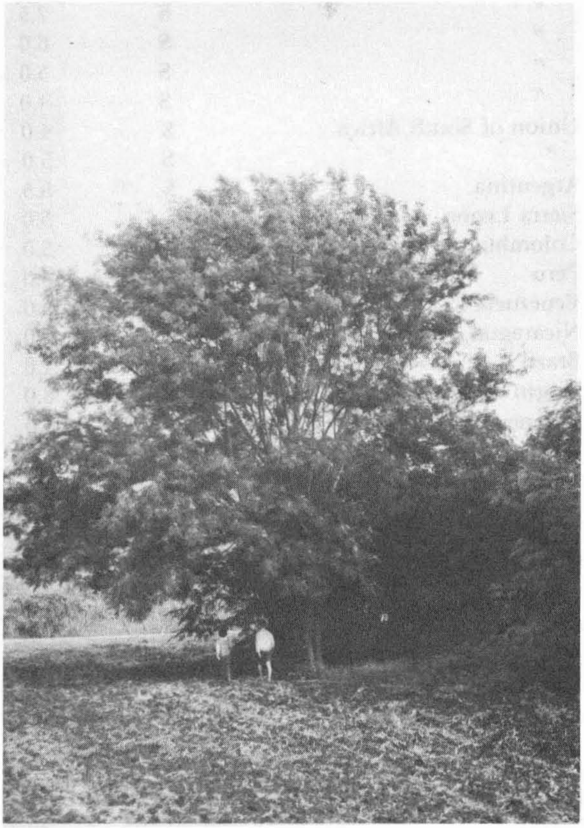

Figure 2. Three-year-old 80-chromosome trees of K19 x K63 (*L. pulverulenta* x *L. leucocephala*).

SUMMARY

Yield trials were conducted in Hawaii of 104 strains of *Leucaena* species (koa haole). Twenty-two of these strains, including the Hawaiian variety as check, were placed in replicated advanced yield trials at 3 locations.

Most varieties significantly outyielded the Hawaiian check in replicated trials, and none of them yielded significantly less. Annual yields of the 3 leading varieties averaged 42 tons of green forage per acre with about 80 percent leaf and green succulent portion. These values represent calculated yields of 10.8 tons dry weight, or 4320 pounds of crude protein per acre per year. Yields were maximal in summer months at lower elevations. It is projected that superior koa haole varieties in Hawaii lowlands will produce 60-ton yields (15 tons dry weight) on an annual basis if irrigated and harvested every 8 or 10 weeks.

APPENDIX

Experiment 1. Observational Nursery, Waimanalo, Oahu, 1963–68

All plant introductions of the genus *Leucaena* were placed initially in an observational nursery at the Waimanalo Experimental Farm (Table 3). Twenty seedlings were transplanted into the 2-row plots, with 3-foot × 6-foot spacing, and the supplemental irrigation was provided only during establishment. The Waimanalo Farm has an average rainfall of 52 inches per year, ranging from 0.5 inch to 15.0 inches per month, with a dry season of about 4 months (May to August). Temperatures average 81 F, with monthly averages ranging from 76 to 85 F. The soil is a dark magnesium silty clay.

Between 1963 and 1968, there were 104 strains studied in this nursery (Table 3). Most accessions were from countries in which the species is widely naturalized but not native. The 104 original strains included the following species (Table 3):

L. leucocephala	90 strains
L. pulverulenta	4 strains
L. lanceolata	1 strain
L. trichodes	1 strain
L. diversifolia	2 strains
L. leucocephala × *L. pulverulenta* (suspected)	4 strains
Prosopis insularum	2 strains

Chromosome counts and hybridization studies of these species have been reported previously (Gonzalez, Brewbaker, and Hamill, 1967). Only *L. leucocephala* and the suspected species hybrids were included in preliminary and advanced yield trials. Mimosine values were computed on many of the strains (Table 3; Brewbaker and Hylin, 1965).

Plant heights are summarized in Table 3 from data collected 6 months after planting. Most of the tall strains were arboreal, while shorter strains were shrubby and abundantly flowering. Arboreal strains such as K28 attained a height of 32 feet in 2 years, with a breast-height diameter averaging 6 inches on unfertilized soils, with no trimming. Forage and timber yields in *Leucaena* would appear to be highly correlated; for example, the heights in Table 3 correlated significantly with the yields in the advanced trials.

Little variation was observed within strains, tending to confirm the self-fertility reported for the species *L. leucocephala* (Gonzalez, 1966; Hutton and Bonner, 1960). When seeds were harvested from *L. pulverulenta* ($2n = 56$) in this nursery, however, they proved to be almost 80 percent cross-fertilized by *L. leucocephala*. The small, open flower of *L. pulverulenta* is evidently more susceptible to outcrossing than that of *L. leucocephala*. Open-pollinated seed on *L. lanceolata* appeared to be entirely selfed.

Genetic variations in the polyploid *L. leucocephala* ($2n = 104$) were largely quantitative, including differences in flowering response to daylength, branching habit, leaf size, leaflet and pinnae number and size, pod length, hairiness, seed number and size, mimosine content, and several other characters. Intraspecies variations in seed and seedling enzymes were very limited (Gonzalez, Brewbaker, and Hamill, 1967). Genetic variations were prominent only among native Central American lines. In contrast, there was essentially no convincing genetic variation among Hawaiian collections, or among collections of the Hawaiian type from Philippines, Australia, Thailand, and other countries. We can only conclude that the Hawaiian type has a very limited germplasm base, perhaps tracing to a single original strain from the center of origin of this species (which appears to be in Guatemala or Southeastern Mexico). This strain of shrubby, heavily flowering material probably was spread west and north in Mexico for its horticultural use by Mayans and other peoples. The shrubby koa haole is a sporadic house or fence plant throughout Latin America that evidently moved with Spanish explorers from ports such as Acapulco and Mazatlán into world trade since the 17th century. The high self-fertility of *L. leucocephala* will have further ensured the comparatively restricted variation of this shrubby type that became pantropical, and that has come to be identified as Hawaiian.

A major objective of our breeding program has been to reduce mimosine levels in koa haole. Mimosine determinations of 72 strains were reported by Brewbaker and Hylin (1965) from this observational nursery; these and other values obtained by Gonzalez (1966) are included with yield data in Table 3.

Experiment 2. Yield Trial, Waimanalo, Oahu, 1964–65

Performance data for 67 varieties of koa haole were recorded by Gonzalez (1966) from a 3-replicate trial at the Waimanalo Experimental Farm, Oahu, planted August 10, 1964. The seed bed was prepared carefully, and seeds (scarified with H_2SO_4) were planted directly 8 inches apart in rows spaced 3 feet apart. Plots consisted of a single 30-foot row. No herbicide, fertilizer, rhizobium treatment, or irrigation was applied. Two cuttings were taken, the first 4 months after seeding, and the second 7 months after seeding. Rainfall was adequate to sustain optimal growth throughout this period.

Yields are summarized in Table 4 for the 67 varieties grown at Waimanalo and the 62 grown at Kapaa (*see* following experiment). Fresh weights were converted to dry weights by the use of 3-pound check samples, oven-dried. Percentages of dry weight of the succulent foliage averaged 25 percent in these experiments. Dry weights ranged from 4.42 tons per acre down to 0.82 ton per acre per cutting (Table 4), which represented a range of 311 percent to 58 percent in proportion of the check Hawaiian variety. The superiority of most introduced lines to the Hawaiian check was apparent; 15 lines significantly exceeded the yield of this check at a 5 percent level, and 7 exceeded it at a 1 percent level. Significance was measured by use of a standard devia-

Table 4. Yields of dry forage in tons per acre per cutting and in percent of check variety, K63, of 70 varieties of koa haole harvested at Waimanalo (2 cuttings, 3 replications) and Kapaa (2 cuttings, 1 replication), 1964-65. Standard deviation in percent of check = 46.5%

	Average plot yield, tons/acre/cutting		
Variety	Waimanalo	Kapaa	Yield in % of check
K67	3.37	5.45	311
K8	3.82	4.85	304
K29	3.05	4.50	266
K28	3.00	4.50	264
K1	2.68	3.40	215
K72	2.15	3.70	206
K6	2.70	3.05	203
K62	2.10	3.15	185
K7	2.37	2.85	183
K3	2.52	2.60	182
K26	1.43	3.40	170
K4	2.30	2.35	163
K13	1.97	2.70	163
K22	1.77	2.55	151
K47	2.03	2.10	146
K70	2.08	2.00	142
K2	2.80	1.25	142
K34	1.50	2.50	141
K16	0.88	3.05	137
K66	2.20	1.70	135
K33	1.35	2.40	134
K21	1.73	2.05	132
K30	1.63	2.15	132
K51	1.48	2.20	128
K56	1.73	1.90	128
K55	1.60	1.95	125
K43	1.83	1.50	118
K58	2.43	0.90	118
K5	2.67	0.65	118
K35	1.63	1.65	118
K59	2.35	1.05	118
K27	1.78	1.45	114
K54	1.45	1.75	113
K32	1.53	1.65	113
K65	1.67	1.65	113
K61	1.63	1.55	111
K39	1.63	1.55	111
K68	1.78	1.25	109

Table 4. Yields of dry forage in tons per acre per cutting and in percent of check variety, K63, of 70 varieties of koa haole harvested at Waimanalo (2 cuttings, 3 replications) and Kapaa (2 cuttings, 1 replication), 1964–1965. Standard deviation in percent of check = 46.5% —Continued

Variety	Average plot yield, tons/acre/cutting		Yield in
	Waimanalo	Kapaa	% of check
K53	1.73	1.30	108
K18	1.62	1.45	107
K60	1.42	1.60	106
K15	1.45	1.55	106
K49	1.70	1.25	104
K57	1.87	0.95	100
K63	1.28	1.60	100 (check)
K42	1.47	1.35	100
K50	1.48	1.25	97
K36	1.20	1.35	90
K41	1.33	1.10	86
K71	1.80	0.55	83
K64	1.55	0.75	81
K44	1.62	0.55	76
K37	1.50	0.60	74
K38	1.18	0.95	74
K52	1.60	0.45	72
K24	1.30	0.70	70
K31	1.52	0.40	69
K17	1.45	0.40	65
K46	0.83	0.80	58
K12	2.65	—	207
K48	2.00	—	156
K45	1.68	—	131
K69	1.65	—	129
K25	1.60	—	125
K23	1.37	—	107
K40	1.30	—	102
K9	1.18	—	92
K10	—	3.0	188
K19	—	2.1	131
K11	—	1.2	75

tion (Table 5) corrected for the $V \times C$ variance component (Satterthwaite, 1946). Analysis of variance of the Waimanalo data from the 2-cutting, 3-replicate experiment is presented in Table 5. Variation among the 67 varieties was highly significant. The mean difference between the 2 cuttings (average 2.28 and 1.40 tons per acre, respectively) was significant at $P<0.05>0.01$ (F value was based on $R \times C$ error term).

The varieties performed similarly in the 2 cuttings, as indicated statistically for example by the lack of significance of mean square (MS) for $V \times C$ interaction. The data and the field observations suggested that advanced yield trials should include 4 or more replications of small plots, with 3 or 4 cuttings. It was instructive to observe from ranked data (Gonzalez, 1966) that selection of the top 20 varieties at Kapaa, in an unreplicated trial, would have included all of the top 7 varieties of the replicated Waimanalo trial. The coefficient of variation for this experiment was 25.1 percent.

Some agronomic characteristics of the top 20 varieties in this trial are summarized in Table 6. It was apparent in the field that nonflowering varieties were generally tall and high in yield, while earlyflowering types (such as the Hawaiian check, which flowered within 6 weeks of each cutting) were low in yield. Dry matter percentages and percentages of edible (i.e., nonwoody) forage were somewhat lower for these top-yielding nonflowering strains, as a result of their woodiness.

Plant heights at cutting time correlated well ($P<0.01$) with forage yields (Gonzalez, 1966). Height differences were obvious within 7 weeks of cutting, and perhaps afford a useful index in selection. Three general growth patterns could be distinguished among the 67 strains; one tall and nonflowering (e.g., strain K8 with midsummer growth of about 10 feet in 12 weeks), one tall and variable in flowering (e.g., strain K72, growing about 8 feet in 12 weeks), and one short and early flowering (e.g., strain K63, growing about 5 feet in

Table 5. Analysis of variance of Waimanalo koa haole yield data summarized in Table 4. Error mean square for varieties (= 0.49) was constructed following method of Satterthwaite (1946)

Source of variation	Degrees of freedom	Mean square	F
Varieties	66	2.00	4.55**
Replications	2	11.74	
Error (a)	132	0.41	
Cuttings	1	78.76	42.12*
Variety X cutting	66	0.25	
Replication X cutting	2	1.87	
Error (b)	132	0.21	

Table 6. Performance statistics of the 20 top-yielding varieties of koa haole and check variety grown at Waimanalo Farm, 1964–65

Variety	Yield in % of check[1]	Plant height in feet[2]	Weeks to flower	Percent dry matter	Percent edible[4]
K67	311	4.8	n.f.[3]	23.7	63.6
K8	304	5.7	n.f.	25.8	58.3
K29	266	5.0	n.f.	23.9	65.4
K28	264	4.7	n.f.	25.4	71.4
K1	215	4.3	n.f.	24.9	70.6
K72	206	3.9	7	24.4	63.6
K6	203	4.2	9	24.9	64.0
K62	185	4.2	n.f.	26.5	63.6
K7	183	3.7	7	26.3	58.3
K3	182	3.9	9	26.3	70.0
K26	170	2.8	8	24.8	81.2
K4	163	4.3	9	24.3	71.4
K13	163	3.1	8	25.1	68.7
K22	151	2.8	8	24.6	73.3
K47	146	3.2	8	26.0	70.6
K70	142	3.5	9	24.4	77.8
K2	142	3.8	9	25.2	66.7
K34	141	3.1	8	25.2	73.7
K16	137	2.4	9	24.8	71.4
K66	135	4.3	8	26.2	63.6
K63 (check)	100	2.7	7	—	—

[1]Averages of Kapaa and Waimanalo trials, from Table 4.
[2]Heights taken on first cutting, after 12 weeks' growth.
[3]n.f. = nonflowering.
[4]Leafy and succulent stem tissue in proportion of total green weight.

12 weeks). These types are quite similar to the Salvador, Peru, and Hawaiian types as viewed by Gray (1967*c*).

Seed weights were computed on 33 strains selected at random, ranging from 3.5 to 6.5 grams per 100 seeds. Seed weight was positively correlated with plant height. In general, the Salvador types had seasonal flowering; reduced seed production; and large flowers, fruits, and seeds. The probable value of seed size as an index of plant vigor and yield deserves further study.

Experiment 3. Yield Trial, Kapaa, Kauai, 1964–65

Performance data for 62 varieties of koa haole were recorded in an unreplicated trial on the Kapaa Experimental Farm, Kauai, planted in October 1964. All except 3 of the varieties were also grown at Waimanalo, Oahu (*see* preceding section). The Kapaa plots were limed to pH 6.0 by an application of

2.5 tons of crushed coral stone, and 250 pounds of phosphorus per acre was applied as rock phosphate. Contact oil sprays were used to control weeds. The experimental site was located at an elevation of 520 feet, where the average rainfall is 92 inches, with monthly averages ranging from 1.5 to 12 inches, and the experiment was not irrigated. Annual temperatures average 72 F, with monthly averages ranging from 66 to 77 F. The soil is a gravelly silty clay of the Aluminous Ferruginous Latosol great soil group. The plots consisted of 2 rows 40 feet long and 3 feet apart, with seeds spaced 8 inches apart. Planting procedures were similar to those on Oahu (Experiment 2). Cuttings were made at 3 months (January 16, 1965) and 9 months (July 29, 1969) following planting.

Yield data have been summarized in Table 4. Average yields of the cuttings differed significantly (0.66 ton and 3.12 tons per acre), largely due to the differences in growing periods. As noted in the previous section, however, average yields from this trial correlated quite well with those of the Waimanalo trial. Woodiness was high and edibility low in the second cutting at Kapaa; average dry weights were 26.1 percent for the first cutting and 32.3 percent for the second. Experience from the 2 trials suggested that the first cutting should be made within 12 weeks of seeding, assuming water and temperatures are not limiting.

Varietal performances in the Kapaa trial were very similar to those of the replicated Waimanalo trials, and the average performance of the two Farms was used as a guide to selection. None of the varieties planted at only one of the two Farms was considered good enough for advance.

Experiment 4. Advanced Yield Trial, Waimanalo, Oahu, 1966-67

Twenty varieties were selected in 1965 from the preliminary yield trial nurseries for inclusion in replicated yield trials at Waimanalo, Oahu (Tables 7 and 8), and at Kapaa, Kauai (Experiment 5). Twelve varieties were planted in each of 4 replications (seeds of one of these, K29, were insufficient for replication at Kapaa). Eight varieties were planted without replication at each Farm for further observation. The local Hawaiian variety, K63, was retained as a check. Two-row plots, 30 feet long, were seeded directly, with a spacing of 4 inches between seeds, and 36 inches between rows.

The Waimanalo planting was made on November 1, 1966, in land previously planted to preliminary koa haole yield trials, with no added fertilization (*see* Experiment 2 for details on this experimental area). No herbicide was used, and weed growth was poorly controlled until after the first cutting, when a contact oil spray was applied. Some contamination occurred from koa haole seeds scattered on this soil during the previous planting. The comparatively slow growth of koa haole in these cool, overcast winter months is an obvious hindrance to the establishment of weed-free fields, and summer plantings would be preferable in this area.

Table 7. Average yields of 12 replicated varieties and 8 unreplicated varieties in 3 cuttings at the Waimanalo Experimental Farm, 1966–67

	Tons/acre/cutting			
Variety	Cutting 1	Cutting 2	Cutting 3	Average in tons/acre/year**
K29	10.10	10.60	8.26	46.0 a
K8	9.39	11.19	8.17	45.7 a
K67	9.30	10.06	8.30	44.4 a
K28	7.48	8.06	6.97	36.3 b
K62	7.41	7.64	6.46	34.5 b
K16*	6.99	7.94	5.86	33.0 bc
K5*	6.32	7.70	5.63	31.4 bcd
K72*	5.87	6.20	4.84	27.0 cde
K3	4.89	5.64	4.95	25.2 de
K30*	5.55	5.46	4.51	24.8 de
K1	4.97	5.76	4.69	24.8 de
K7	4.90	5.43	4.48	23.9 de
K58*	4.57	5.46	4.32	23.1 ef
K22*	3.53	5.22	4.91	22.8 ef
K59*	4.14	4.76	4.13	21.2 ef
K63	4.45	4.69	3.88	20.9 ef
K4	4.19	5.00	3.25	19.5 ef
K13	3.58	3.15	3.27	16.3 f
K6	2.52	5.03	2.60	15.9 f
K2*	3.12	2.03	2.93	15.7 f
% Dry weight	28.6%	32.6%	30.8%	30.67%

*Unreplicated varieties.

**Computed as in Table 2; averages which do not have letters in common are significantly different: ($P=0.05$), $S_{\bar{x}}=2.43$ tons/acre/year.

Table 8. Analysis of variance of Waimanalo koa haole yield data summarized in Table 7

Source of variation	Degrees of freedom	Mean square	F	P
Varieties	11	4,678.2	20.52	0.01
Replications	3	5,219.9		
Error (a)	33	288.0		
Cuttings	2	1,639.0	2.99	0.05
Variety X cutting	22	75.5		
Replication X cutting	6	547.8		
Error (b)	66	88.0		

The first cutting at Waimanalo was taken at 94 days (February 2, 1967); the second cutting was made in 92 days (May 5), and the final cutting in 53 days (June 27). Differences in growth rate during these periods were noted earlier (Table 2); the superior performance of the 53-day summer cutting was evident, both in its high yield per day of growth and in the high quality of the harvested forage.

Yields of 7 varieties significantly exceeded that of the check, and 3 of those (K8, K29, and K67) were clearly and consistently superior to all other varieties and in nearly all cuttings (Table 7). On an annual basis, these varieties yielded 46.0, 45.7, and 44.4 tons per acre. These estimates may be considered conservative, since the growth to first cutting is always slow, and since a disproportionate fraction of the experiment occurred in cool, overcast winter months. At the other extreme, for example, extrapolation from yield values for the third cutting period (53 days, in summer) provides upper yield estimates for this trial of 56.2, 56.9, and 57.2 tons per acre per year, for K8, K29, and K67, respectively.

Analysis of variance of the fresh weight yields summarized in Table 7 is provided in Table 8. Differences among varieties were highly significant (error variance was constructed following the model of Satterthwaite 1946). Averages for the 3 cuttings were not significantly different, as tested on the replication × cutting error term ("fixed model"). Coefficient of variation for the experiment was 18.5 percent. Average yields of the 4 replications were similar except for one high-yielding replication (44.4, 44.5, 44.9, and 68.7 pounds per plot, respectively).

Dry weight percentages in the Waimanalo yield trial were relatively high, averaging 30.7 percent for the 3 cuttings (Table 7). Calculations of edibility were based on the woody portions of dry weights, which averaged about 30 percent (cuttings ranged from 29 to 35 percent). It is apparent that tall-growing varieties develop large amounts of wood rapidly, and studies on the timing of harvest on yield and edibility are needed.

Experiment 5. Advanced Yield Trial, Kapaa, Kauai, 1966–67

Twenty-two varieties were selected in 1965 from preliminary yield trials for inclusion in this study (Tables 8 and 10). Eleven varieties were planted in 4 replications each, and 11 varieties were planted without replication, in an augmented block design. The local Hawaiian variety, K63, was planted as a check. Two-row plots, 40 feet long, were seeded directly, with a spacing of 10 inches between seeds and 36 inches between rows.

Planting on the Kapaa Farm was made on March 20, 1966, in land previously planted to koa haole preliminary yield trials, with no irrigation (*see* Experiment 3 for details on this experimental area). Stands were satisfactory; weed growth was controlled by hand or by use of contact oil sprays. Cuttings were made on July 11, 1966; October 17, 1966; February 9, 1967; June 26,

Table 9. Average yields of 11 replicated varieties and 11 unreplicated varieties in 5 cuttings at the Kapaa Experimental Farm, 1966–67

Variety	Tons/acre/cutting					Average in tons/acre/year
	Cutting 1	Cutting 2	Cutting 3	Cutting 4	Cutting 5	
K8	17.02	13.08	10.22	13.07	19.74	38.32 a
K28	15.05	12.71	9.87	11.84	17.20	35.06 ab
K67	15.53	12.44	8.06	11.06	16.88	33.67 b
K62	14.01	9.70	8.16	10.24	14.23	29.52 c
K5*	10.80	10.62	8.17	9.53	15.06	28.47 c
K2*	9.39	8.58	7.67	11.16	15.34	27.02 c
K29*	7.53	8.62	6.22	8.80	12.07	22.63 d
K72*	8.12	6.83	7.71	9.44	10.71	22.06 d
K58*	8.94	7.01	6.44	8.71	9.89	21.39 d
K12*	7.40	—	5.04	5.99	15.34	20.04 de
K22*	6.49	5.40	5.22	6.35	15.34	19.96 de
K1	6.86	6.03	5.16	8.09	12.51	19.95 de
K3	6.08	7.22	6.03	8.18	10.66	19.90 de
K6	8.49	6.53	5.06	7.09	10.12	19.48 de
K59*	7.40	4.81	6.72	8.44	9.53	19.02 de
K7	8.76	6.63	5.21	6.61	8.10	18.58 de
K4	7.11	5.45	4.38	5.47	9.06	16.45 ef
K13	5.82	4.17	3.71	5.30	8.12	14.06 fg
K63	6.43	4.32	3.20	4.43	6.03	12.81 fg
K16*	2.22	4.08	2.72	5.31	10.07	12.49 fg
K26*	3.90	4.72	2.99	4.36	5.17	11.15 g
K30*	2.77	3.18	3.22	4.72	5.90	10.20 g
% Dry weight	26.5%	23.5%	24.1%	26.9%	26.8%	25.56%

*Unreplicated varieties.

**Computed as in Table 2; averages which do not have letters in common are significantly different: (P = 0.05), $S\bar{x}$ = 1.35 tons/acre/year.

Table 10. Analysis of variance of Kapaa koa haole yield data summarized in Table 9

Source of variation	Degrees of freedom	Mean square	F
Varieties	10	28,316.62	6.47**
Replications	3	17,145.40	
Error (a)	30	4,378.78	
Cuttings	4	25,910.81	24.29**
Variety X cutting	40	694.00	
Replication X cutting	12	1,066.65	
Error (b)	120	792.24	

1967; and October 31, 1967 (*see* Table 2). As noted earlier, growth was obviously slower in the cooler months.

Yields of 16 of the 22 varieties significantly exceeded that of the check, and 3 of these (K8, K28, and K67) were clearly and consistently superior in all cuttings. The variety K8, a Salvador type from Mexico, was top performer among these 3 varieties, as it was in the Waimanalo trial in every cutting at each Farm (exceeded once by K29, a variety included at the Waimanalo Farm only). Annual yields at Kapaa and Waimanalo may be considered conservative, due to the downward bias of the first-cutting data and lower winter growth. Extrapolation of growth in the second cutting (97 days) provides upper yield estimates for this trial of 49.2, 47.8, and 46.8 tons per acre per year, for K8, K28, and K67. These yields were significantly below those at Waimanalo, and it is probable that maximum yields of koa haole will be obtained in hot, lowland areas similar to those in which the species is most widespread naturally.

Analysis of variance of the fresh weight yields in Table 9 is given in Table 10. Differences among varieties were highly significant (error variance was constructed following the model of Satterthwaite, 1946). The cutting averages were also significantly different. Coefficient of variation of this experiment was high, 28.5 percent, evidently due to the large variation among varieties within replications in the first cutting (rates of establishment were highly variable in this experimental area). Average yields of the 4 replications throughout the experiment, such as those at Waimanalo, were similar except for 1 replication (79.3, 79.4, 85.7, and 114.3 pounds per plot, respectively). Both of these sets of data emphasize the fact that field variations in fertility, not immediately interpretable, could raise koa haole yields impressively (54 percent in the Waimanalo trial, 40 percent at Kapaa).

Statistically, the two advanced yield trials were relatively similar when correction was made for differences in plot size (180 vs. 240 square feet). Comparing varietal performance in the preliminary and advanced yield trials, there were few changes of consequence in varietal ranking. Certain varieties (e.g., K1 and K6) performed well in preliminary trials but poorly in advanced trials, while the rankings of others (e.g., K5) were inconsistent. Comparing varietal performances in the two advanced yield trials, the only striking discrepancies were provided by varieties K29, K16, and K2. The variety K29 had performed well in preliminary trials and was excellent in replicated advanced trials at Waimanalo, but was less impressive in the nonreplicated advanced trials at Kapaa. The varieties K2 and K6 performed very differently in the two advanced trials, but each had been variable in preliminary trials also.

Varieties emerging from all trials as superior were K8, K28, K67, K29, and K62. Seeds of these strains have been increased, and small seed lots can be obtained from the U.S. Department of Agriculture or the authors.

Experiment 6. Performance Trials on Maui

Twelve varieties from observational nursery trials were grown in a nonreplicated test at the Plant Materials Center, Wailuku, Maui, by the Soil Conservation Service, U.S. Department of Agriculture.[2] Nine harvests were made of this trial over a 24-month period (planting date, September 27, 1965). The Plant Materials Center is located at sea level on a Pulehu silty loam soil with neutral pH, and has an annual rainfall of 13 inches. Supplemental irrigation was provided only for the first 5 cuttings. Three-row plots, 50 feet long with 40 inches between rows, were direct-seeded at a 4-inch spacing. The central row of each plot was harvested for green weight records when it had attained a height of about 5 feet.

Yields were abstracted from the unpublished report of Lewis and Palmer (1968) for Table 11. Data from the first cutting were omitted, providing 4 harvests with, and 4 without, supplemental irrigation. Averages were computed and compared with check K63 and with data from other yield trials (Tables 7 and 9).

It was evident that yields under irrigation exceeded those without irrigation (by 28.7 percent), although the strong koa haole taproots probably reach water table in this area. As might be predicted, the highest yielding strains appeared more sensitive to water stress, although maintaining their yield superiority

[2]The authors acknowledge with thanks the excellent cooperation of the Soil Conservation Service in these trials, and in particular that of Mr. Earl A. Lewis.

Table 11. Average green weights of 12 varieties of koa haole in 8 cuttings on Maui, 1965–67

	Tons fresh weight/acre/year*			Yield in % of K63 (check)		
Variety	Irrigated	Nonirrigated	Average	Maui	Kauai	Oahu
K8	51.3	38.0	44.7	121.5	299.1	218.7
K6	50.5	37.7	44.1	119.8	152.1	76.1
K4	43.5	43.5	43.5	118.2	128.4	93.3
K67	50.5	36.0	43.3	117.7	262.8	212.4
K62	47.1	39.2	43.2	117.4	230.4	165.1
K28	51.9	33.0	42.5	115.5	273.7	173.7
K7	49.6	34.7	42.2	114.7	145.0	114.4
K3	47.8	34.1	41.0	111.4	155.3	120.6
K1	40.9	38.3	39.6	107.6	155.7	118.7
K63	39.0	34.5	36.8	100.0	100.0	100.0
K13	42.9	30.2	36.6	99.5	109.8	78.0
K99	26.9	21.8	24.4	66.3	—	—

*Averages of 4 cuttings each were converted to per-annum basis for the irrigated and nonirrigated columns.

under both conditions. Several varieties showed little response to irrigation, notably K4.

Using average values from both irrigated and nonirrigated cuttings, the varieties K8 and K6 were superior; strains K4, K67, K62, and K28, however, were not significantly lower in yield. Lewis and Palmer (1968) considered strains such as K8 and K28 rather too woody, and expressed preference for the strain K6, with its low-branching habit. This Peru strain (from a New Guinea collection tracing back to Australian introductions) appeared erratic and somewhat less impressive in our other tests. The so-called Peru type performs well in Australia, and is considered superior breeding material by Gray (1967*a*) in production of vigorous shrubby types of this legume. These lines deserve entry in tests assessing maximal yields in the tropics under diverse management conditions.

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