University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Papers from the University Studies series (The University of Nebraska) University Studies of the University of Nebraska

3-1969

The Genus Carduus L. in Nebraska

Marian Jane Fuller
University of Nebraska - Lincoln

Follow this and additional works at: https://digitalcommons.unl.edu/univstudiespapers

Part of the Arts and Humanities Commons, and the Weed Science Commons

Fuller, Marian Jane, "The Genus Carduus L. in Nebraska" (1969). *Papers from the University Studies series (The University of Nebraska)*. 26.
https://digitalcommons.unl.edu/univstudiespapers/26

This Article is brought to you for free and open access by the University Studies of the University of Nebraska at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Papers from the University Studies series (The University of Nebraska) by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

UNIVERSITY OF NEBR
LIBRARY
MAY 6 1969
ARCHIVES

Marian Jane Fuller

The Genus *Carduus* L. in Nebraska

new series no. 39
University of Nebraska Studies
march 1969

THE GENUS *CARDUUS* L. IN NEBRASKA

Marian Jane Fuller

THE GENUS *CARDUUS* L. IN NEBRASKA

university of nebraska studies : new series no. 39

published by the university
at lincoln : march 1969

The University of Nebraska

The Board of Regents

J. G. Elliott
B. N. Greenberg, M.D.
Richard L. Herman
Robert L. Raun
Edward Schwartzkopf

Richard E. Adkins, *president*
G. Robert Ross, *corporation secretary*

The Chancellor

Merk Hobson, *acting**

*Chancellor Clifford M. Hardin on leave as Secretary of Agriculture in the Cabinet of the President of the United States.

Acknowledgments

The writer wishes to express her appreciation to the following people whose generous assistance made this study possible:

Dr. J. F. Davidson under whose direction and counsel this study was made, under whose gentle nudging the fears of the computer were overcome, and under whose red ink pen this paper gradually took shape;

Dr. M. K. McCarty (Department of Agronomy) who originally indicated the problem in *Carduus* and who helped in obtaining background for this study;

Mr. Roy Hallquist and the entire University of Nebraska Computer Center personnel for their aid in setting up programs, their unfailing generosity of time, and their constant willingness to drop their current activities in order to assist a mere neophyte;

Dr. Sue Tolin (Virginia Polytechnic Institute) and Mr. James Congroves (Department of Agronomy) for their assistance in collecting material;

Mr. Glen Drohman who is in charge of the Botany greenhouse for his help in the handling of living material.

Contents

List of Figures

List of Tables

List of Plates

Introduction

The genus *Carduus* L., a member of the Compositae, consists of approximately 120 species native to Europe (Arenes, 1949; Mulligan and Frankton, 1954). Of these, *C. acanthoides* L., *C. crispus* L. and *C. nutans* L., have been introduced to North America, but only *C. acanthoides* and *C. nutans* have been reported in Nebraska.

A general description of the Nebraska members of this genus is as follows: annuals or biennials; herbaceous stems spiny winged; leaves lobed with spiny margins; heads solitary or clustered at end of branches; phyllaries imbricated, spine-tipped in many rows; florets tubular, perfect, usually purple, rarely white; cypsela oblong, glabrous, with shallow longitudinal grooves; pappus of simple, denticulate hairs in many rows.

From field observations, it appeared that the seeds of *Carduus* normally germinate in mid-summer and then the plant passes through the following winter in a rosette stage. In the spring the plant may or may not bolt and produce flowers. If it does not bolt, then it passes through the next winter still in the rosette stage.

According to present evidence, members of the genus *Carduus* were introduced into Nebraska in the early 1930's, but they posed no significant problem until recently. However, since approximately 1958, the population has demonstrated a dramatically rapid increase from a few scattered members in the southeast portion of the state to large stands covering up to twenty or more acres. This increase has become so great that in 1966, upon the recommendation of the Nebraska Extension Weed Control, the genus was placed on the Nebraska list of noxious weeds.

In the spring of 1965, M. K. McCarty (University of Nebraska Department of Agronomy) and J. F. Davidson (University of Nebraska Department of Botany) suggested the possibility of attacking the *Carduus* problem. During ensuing discussions, three major possibilities as to the cause of the rapid increase in population size were considered. The possibilities discussed were: 1) the species had been recently introduced into this area; 2) new farming practices had been employed which opened up new and less selective environments suitable for their growth and development; 3) via interbreeding, new germ plasm had been introduced which increased the

tolerance ranges of the offspring, thus allowing them to grow in previously intolerable environments.

The first possibility was eliminated after a survey was made of the specimens of *Carduus* in the Nebraska State Herbarium. The first record of *C. acanthoides* was from Lancaster County in 1930, and the first record of *C. nutans* was in 1932 from Seward County. Therefore, members of this genus have been present in the state for more than thirty years. After discussing the agricultural practices in the state with various persons in the University of Nebraska Department of Agronomy and various farmers throughout the state, it was decided that the agricultural practices have not been changed radically enough in the past few years to allow for the rapid population increase. Therefore, tentatively, this second possibility was eliminated. In order to determine whether the introduction of new germ plasm was the cause of this expansion of the population of *Carduus*, the relationships existing among the members of this population had to be ascertained.

It was noted on initial collection trips, taken in the spring of 1965, that the plants showed a great amount of variation in leaf and head characters. Also, these plants were generally located in overgrazed pastures, road and railroad rights-of-way, and along eroded stream banks. Thus, these preliminary investigations gave every indication that this population might possibly be of hybrid derivation. This assumption was based on past experiences with the known *Helianthus annuus X petiolaris* hybrids which were found in recently disturbed areas and the records of other hybrid derivatives which also populated such areas (Anderson, 1949).

A sample of the *Carduus* population was made throughout the state of Nebraska. Collections were made in thirty-five counties while the author was making a survey of eighty-two of the ninety-three counties in Nebraska (Fig. 1). Because of restricted finances and the limited length of the growing season, several areas in the northern part of the state were not sampled.

The area most extensively covered in this survey was the Nebraska Sandhills in the central portion of the state. No stands of *Carduus* were found in the sandhill soil type, although, as shown in Figure 2 (p. 2), three collections were made in the sandhills region. These stands were located in the heavier soils found along river or stream beds. No stands of *Carduus* were found in the Colorado-Nebraska Sandhills in the southwest portion of the state. Hence, it appeared that soil type might have been a factor restricting the spread of these plants into the sandhill areas.

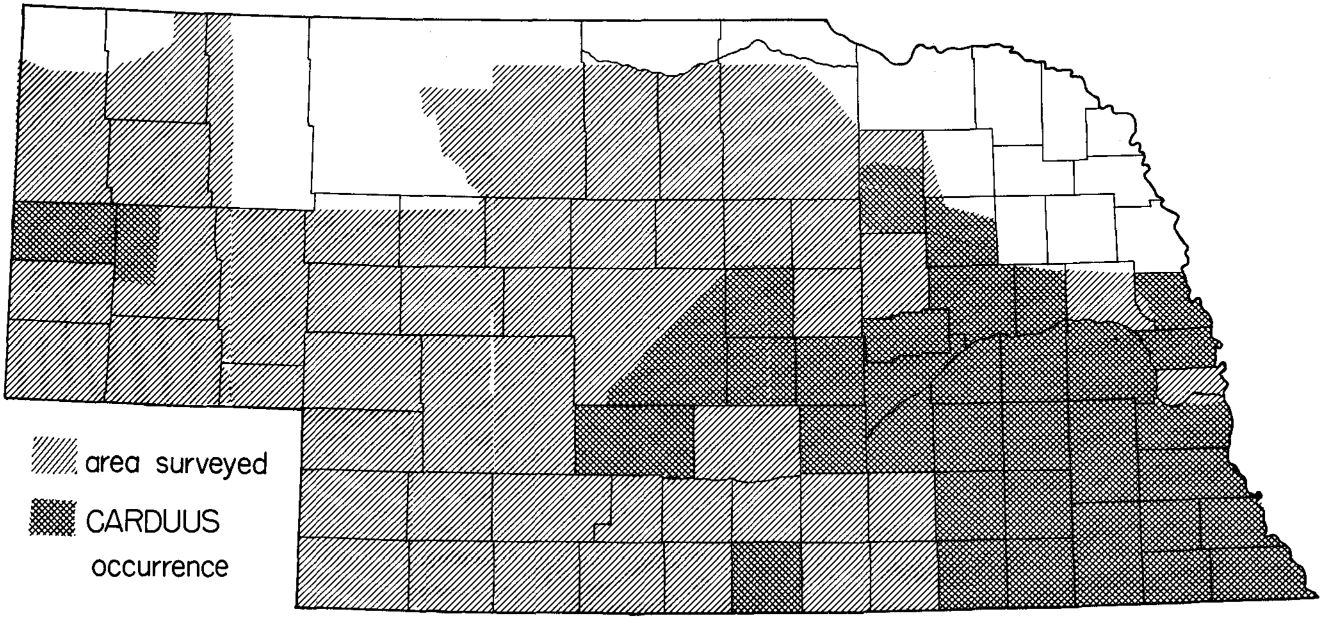


FIG. 1. Map of Nebraska showing area surveyed and the regions in which specimens occurred.

Collections

Materials for use in this work were collected at forty-one different sites throughout the state of Nebraska (Fig. 2). The distribution of *Carduus* over the state ranged from the extreme southeastern to the northwest panhandle. Moving northward to westward from the southeastern portion of the state, there appeared to be a trend from stands in which the plants were very dense to stands in which the plants were scattered. Those areas in the central and western parts in which specimens were found tended to be along the Platte and North Platte Rivers and their tributaries.

Generally, the stands of *Carduus* were found in disturbed areas. Most of the sites were overgrazed pastures or along railroad rights-of-way. The exceptions were collections sites 9, 10, and 11 which appeared to be undisturbed prairies. At these sites there were open areas available in which the *Carduus* plants could have become established.

Table 1 shows the collection number, the location of each site, a description of both the site and the density of the stand of *Carduus*, and the type of material collected from each site. The collection number was made up of the site number and a letter. For example, the first specimen collected at a site was given the site number and the letter A, the second specimen at that site was labelled B, the third C, and so forth.

For describing the density of the stands, the following botanical survey symbols were used:

** – very profuse throughout the region
(**) – very profuse locally
* – profuse throughout the region
(*) – profuse locally
+ – common throughout the region
(+) – common locally
– – scarce throughout the region
(–) – scarce locally
(·) – only one specimen

An example of the interpretation of this code is: +, (**), specimens are common throughout the region, but very profuse in localized

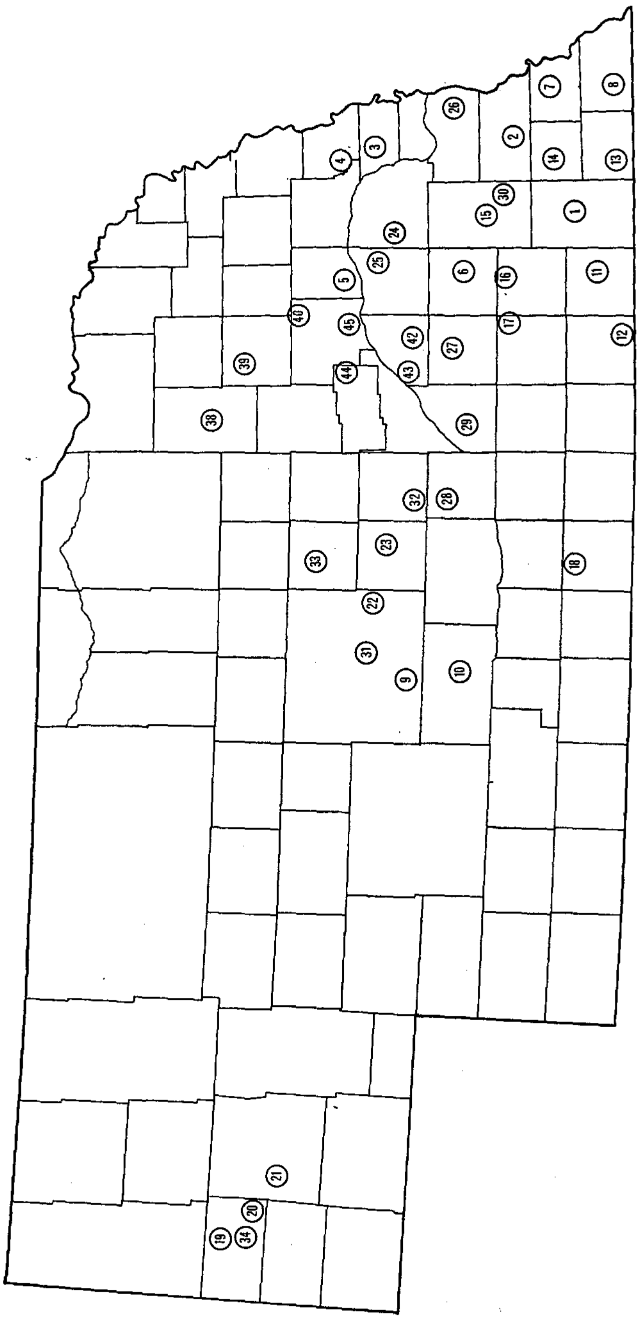


FIG. 2. Collection sites in Nebraska.

areas. A situation in which the density of the stand varies from scarce on the hilltop to profuse in the swale is shown as follows: +, (−) to (*).

The size of each collection depended on the size of the stands which ranged from one to several thousand plants. The method used in collecting specimens three feet or taller for pressing was: 1) recording the height of the plant; 2) recording the number of heads on the plant; 3) removing and pressing the leaves from one side of the plant; 4) removing and pressing a branching section of the stem the size of the press; 5) removing and pressing the terminal head with its peduncle. In those cases where the terminal head was indistinguishable, several heads were removed and pressed. For smaller plants, the method was to trim off enough of the leaves and branches to allow for proper pressing.

At most of the sites, several plants in the rosette stage were dug up, potted, and placed in the greenhouse for further observations. From one site, two mature plants, bearing flowering heads, were brought in and transplanted to a garden. These plants were used for determining pollination mechanisms.

Buds in different stages of development were collected and placed in screw-top jars filled with Carnoy's solution. Before the plants were pressed, the buds were removed and were given the same collection number as the pressed specimen. These buds were used for cytological studies.

Collections included 302 pressed specimens, thirty-four living specimens, and thirty-four jars of buds.

TABLE 1

COLLECTION DATA FOR MATERIAL PRESENTED

Collection No.	Location	Description	Material Collected
1a–1j	GAGE COUNTY 5.2 miles east of Beatrice on State Hiway 4; north side of road.	Heavily overgrazed pasture; gently sloping creek bottom; **,(**).	10 pressed specimens.
2a–2j	OTOE COUNTY 2.9 miles south of Syracuse on State Hiway 50; west side of road.	Overgrazed brome pasture; sloping creek bottom; +,(*).	10 pressed specimens.
3a–3e	DOUGLAS COUNTY 1 mile north of Elkhorn on State Hiway 31; east side of road.	Heavily overgrazed bluegrass pasture; hillside to drainage ditch; +,(+) to (*).	5 pressed specimens.
4a–4e	WASHINGTON COUNTY in Arlington; a vacant lot across from Freddie's Cafe.	Flat bottom brome land; +,(**).	5 pressed specimens.

TABLE 1 *(continued)*

Collection No.	Location	Description	Material Collected
5a–5d	COLFAX COUNTY 7 miles west of Schuyler on U.S. Hiway 30, then 7 miles north on county road.	Slightly overgrazed brome pasture; along ditch right-of-way; +, (*).	4 pressed specimens.
6a–6e	SEWARD COUNTY 0.3 mile south of junction of State Hiways 515 and 15; west side of road.	Pasture overgrown with timber; creek bottom; –1 acre; –,(+).	5 pressed specimens.
7a–7k	NEMAHA COUNTY 2 miles north of Auburn on U.S. 75, then 0.3 mile on county road; south side of road.	Slightly overgrazed brome pasture; hilltop to creek bottom; +,(*).	11 pressed specimens; buds from 7a, 7b; 2 living specimens.
8a–8j	RICHARDSON COUNTY 2.2 miles south of Dawson on State Hiway 75, then 1.2 miles west on county road; south side of road.	Ungrazed brome pasture; flat area; +,(**).	10 pressed specimens; buds from 8a, 8b, 8c; 2 living specimens.
9a–9j	CUSTER COUNTY 1 mile west of Oconto on State Hiway 40, then 3 miles south on county road; west side of road.	Ungrazed prairie; area between two small hills; –, (–) to (+).	10 pressed specimens; buds from 9a, 9b, 9c; 2 living specimens.
10a–10j	DAWSON COUNTY 13 miles north of Lexington on State Hiway 21; west side of road.	Slightly grazed prairie; small ravine; –,(+).	10 pressed specimens; buds from 10a, 10b, 10c; 2 living specimens.
11a–11j	JEFFERSON COUNTY 3 miles north of Harbine on county road; east side of road.	Ungrazed pasture; hilltop to ditch; +, (**).	10 pressed specimens; buds from 11a, 11b, 11c; 2 living specimens.
12a–12j	THAYER COUNTY 3 miles north of Hubbell on county road; east side of road.	Previously overgrazed bluegrass pasture; hilltop to ditch; +,(–) to (**).	10 pressed specimens.
13a–13j	PAWNEE COUNTY 2 miles west of junction of State Hiway 8 and 99; north side of road.	Old abandoned school yard; +,(+).	10 pressed specimens.
14a–14j	JOHNSON COUNTY 1.8 miles east of St. Mary on State Hiway 41, then 2 miles north on county road; east side of road.	Overgrazed bluegrass pasture; south slope of hill; +,(+).	10 pressed specimens.

TABLE 1 *(continued)*

Collection No.	Location	Description	Material Collected
15a–15j	LANCASTER COUNTY South of intersection of State Hiway 2 and 40th Street of Lincoln.	Area between railroad tracks and drainage ditch; –,(+).	10 pressed specimens; buds from 15b, 15c; 2 rosettes; 1 flowering stage.
16a–16k	SALINE COUNTY 9 miles south of Milford on U.S. Hiway 6; east side of road.	Drainage area and eastern slope of adjacent hill; 5 acres; –, (+).	11 pressed specimens; buds from 16a, 16b; 2 living specimens.
17a–17j	FILLMORE COUNTY 2.7 miles east of Sutton on U.S. Hiway 6, then 5.7 miles south on county road; east side of road.	Lightly grazed bluegrass pasture; 10 acres; –,(+).	10 pressed specimens; buds from 17b, 17c; 2 living specimens.
18a–18j	FRANKLIN COUNTY Game Control Area; 2.7 miles east of junction of State Hiways 4 and 10 on Hiway 4.	Lightly grazed brome pasture hilltop to swamp; 5 acres; –,(+).	10 pressed specimens; buds from 18b, 18c; 2 living specimens.
19a–19c	SCOTTS BLUFF COUNTY 4 miles north of Scottsbluff on State Hiway 81, then 2 miles west on county road; east side of pond on G. B. Fuller farm.	Lightly grazed brome pasture; atop slight hill; –,(–).	3 pressed specimens; buds from 19a; 1 living specimen.
20a–20g	SCOTTS BLUFF COUNTY 2.3 miles east of McGrew on State Hiway 92; north side of road.	Area between Hiway and railroad tracks; –, (–).	7 pressed specimens; buds from 20a; 1 living specimen.
21a–21d	MORRILL COUNTY 2 miles west of Bridgeport on State Hiway 92; north side of road.	Pasture overgrown with timber; –,(–).	4 pressed specimens; buds from 21a; 1 living specimen.
22a	CUSTER COUNTY 2.8 miles east of Ansley on State Hiway 2; north side of road.	Overgrazed pasture near barnyard; (·).	1 pressed specimen.
23a–23i	SHERMAN COUNTY 1.7 miles east of junction of State Hiways 92 and 505 on Hiway 92; north side of road.	Lightly grazed prairie; ravine and north and south slopes; –,(–).	9 pressed specimens; buds from 23a; 1 living specimen.
24a–24j	SAUNDERS COUNTY Junction of State Hiway 79 and U.S. Hiway 30a; south corner.	Lightly overgrazed pasture; hilly area; some evidence of spraying; –,(–).	10 pressed specimens; buds from 24a, 24b, 2 living specimens.

TABLE 1 *(continued)*

Collection No.	Location	Description	Material Collected
25a–25k	BUTLER COUNTY 2 miles west of Buro on county road; south side of road.	Area near creek bed; 5 acres; +,(**).	11 pressed specimens; buds from 25a, 25b; 2 living specimens.
26a–26i	CASS COUNTY 12.3 miles west of junction of State Hiways 1 and 73; north side of road.	Overgrazed, eroded pasture; previously sprayed; hilltop to hill base; +,(–) to (+).	9 pressed specimens; buds from 26a, 26b; 2 living specimens.
27a–27e	YORK COUNTY 1 mile north of junction of U.S. Hiways 34 and 81 on 81, 1 mile east and then 0.5 mile on county road; west side of road.	Overgrazed bluegrass pasture along creek bottom; 4–5 acres; –, (–).	5 pressed specimens; 2 living specimens.
28a–28g	HALL COUNTY 7.9 miles south of Cairo on State Hiway 11, then 9 miles east on paved county road; south side of road; 1.8 miles east of U. S. Gov. Reserve.	Overgrazed level pasture; –, (–).	7 pressed specimens; buds from 28a; 2 living specimens.
29a–29j	HAMILTON COUNTY 7 miles west of Aurora on State Hiway 2; north side of road.	Overgrazed brome pasture; sloping terrain; 5 acres; –,(+).	10 pressed specimens.
30a–30h	LANCASTER COUNTY Just south of Cheney city limits; west side of county road.	Heavily overgrazed brome pasture; **, (**).	8 pressed specimens.
31a–31c	CUSTER COUNTY 2 miles south of Broken Bow on State Hiway 2; east side of road.	Overgrazed pasture along a creek bottom; –,(–).	3 pressed specimens.
32a–32j	HOWARD COUNTY 7.8 miles north of Cairo on State Hiway 11; west side of road.	Overgrazed prairie hilltop to wet ravine; 20 acres; –,(–) to (+).	10 pressed specimens; buds from 32a; 2 living specimens.
33a–33g	VALLEY COUNTY 4 miles west of Ord on county road to Sargent; north side of road.	Overgrazed prairie in a small draw; barely visible from road; 2 acres; –,(–).	7 pressed specimens; buds from 33a; 2 living specimens.
34a–34c	SCOTTS BLUFF COUNTY South 5th Avenue in Scottsbluff; south side of road, just north of North Platte River.	Heavily overgrazed brome pasture; flood plain; –,(–).	3 pressed specimens.
38a–38g	ANTELOPE COUNTY 0.3 mile west of Neligh on U.S. Hiway 275; under a bridge.	Overgrazed brome pasture; creek bottom—evidence of overflow; 1 acre; –,(+).	8 pressed specimens.

TABLE 1 *(continued)*

Collection No.	Location	Description	Material Collected
39a–39c	MADISON COUNTY 2 miles west of Battlecreek junction on U.S. Hiway 275; south side of road.	Heavily overgrazed brome pasture; 10 acres; –,(–).	3 pressed specimens.
40a–40e	PLATTE COUNTY 1 mile north of Creston on State Hiway 91; north side of road.	Annually mowed brome pasture; between the railroad tracks and ditch bank; –,(–).	5 pressed specimens.
42a–42g	POLK COUNTY 2 miles east of Stromsburg on county road connecting with 9th Street; north side of road.	Overgrazed brome pasture; hilly area; 15 acres; –,(+).	7 pressed specimens; buds from 42a; 2 living specimens.
43a–43h	POLK COUNTY 6 miles east of Platte River Bridge on U.S. Hiway 30a, then 2.2 miles north on county road.	Slightly overgrazed native prairie; quite hilly area; 20 acres; –, (–) to (+).	8 pressed specimens; 2 living specimens.
44a	NANCE COUNTY On State Hiway 22 just inside the Geneva city limits; west side of road.	On the edge of a recently harvested oat field; –,(·).	1 pressed specimen.
45a–45c	PLATTE COUNTY 1.5 miles west of junction of State Hiway 81 and U.S. Hiway 30 near Columbus; south side of road.	Overgrazed bluegrass pasture; railroad right-of-way; 2 acres; –,(*).	3 pressed specimens; 2 living specimens.

Analysis

Morphological Analysis

The analysis of the morphological data from vegetative and floral characters was done by utilizing an IBM 7040 computer and was checked against conventional methods. With the appreciation of the fact that some measured variation may have been governed by the environment, and some may have been characters that vary at random throughout the genus and hence may not be applicable to the problem at hand, a preliminary analysis was run to check on the validity of the forty-one characters measured. The data from this study were used to check the applicability of the various computer programs to character analysis.

The Preliminary Study

In the preliminary study 100 specimens from the collection, with at least one specimen from each collection site, were selected at random. Every specimen was measured for each of the forty-one characters listed in Table 2 on the following page.

Since the forty-one characters were common to all of the specimens, it was necessary to determine whether any of the characters would tend to divide the sample into two or more groups, or whether the characters showed a continuous range of variation. The pattern of character distribution was determined by checking the frequency distribution of each character.

At the University of Nebraska Computer Center, a program for the IBM 7040 computer prepared by Dale Nelson, a university programmer, tabulated not only the frequency distribution for up to 100 characters (variables), but also computed the mean, the variance, and the standard deviation for each of the variables (the TAL program).

To utilize the computer, the data collected from each specimen had to be transferred to IBM computer cards. The data collected from each specimen had been recorded in tabular form so that they were easily transferred to the IBM cards. The card has eighty columns, each of which can be punched either numerically, 0–9, or alphabetically, A–Z. Each character was assigned to a series of two or three columns on the card depending on the number of integers which were used in recording the character value.

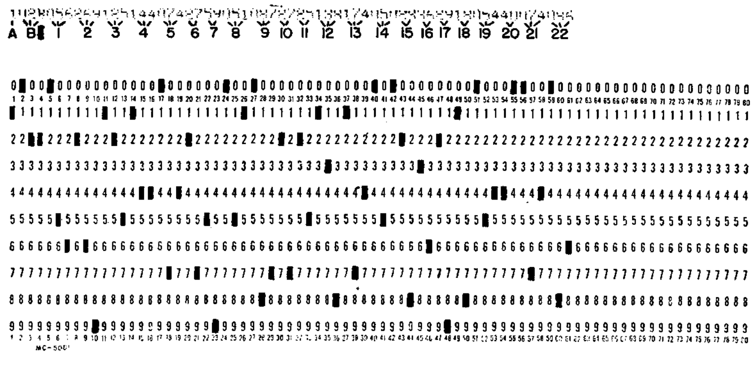
TABLE 2

CHARACTERS AND THEIR IDENTIFICATION NUMBERS USED IN THE STUDY OF 100 SPECIMENS.

Characters	Id. No.	Characters	Id. No.
Phyllary contraction	1	Spine length / Stem diameter	21
Corolla length	2	Peduncle length	22
Expanded length of corolla	3	Leaf length	23
Non-expanded length of corolla	4	Leaf lobe length	24
Corolla lobe length	5	Cor. leaf lobe length	25
Corolla lobe length / Corolla length	6	Leaf lobe width	26
Corolla lobe length / Expanded length	7	Cor. leaf lobe width	27
Corolla lobe length / Non-expanded length	8	Sinus depth of leaf	28
Expanded length / Non-expanded length	9	Cor. sinus depth	29
Head diameter	10	Distance from sinus to sinus of leaf	30
Pappus length	11	Cor. distance from sinus to sinus	31
Phyllary blade length	12	Leaf webbing width	32
Phyllary length	13	Cor. leaf webbing width	33
Phyllary blade width	14	Degree of lobe overlapping	34
Phyllary base width	15	Cor. degree of overlap	35
Phyllary blade shape	16	Leaf tip length	36
Phyllary shape	17	Cor. leaf tip length	37
Phyllary spine length	18	Angle of leaf tip	38
Stem diameter	19	Leaf tip width	39
Stem spine length	20	Cor. leaf tip width	40
		Leaf tip shape	41

In the case of the forty-one characters, it was found that, since 114 columns were needed for the data from one specimen, two cards were required to represent each plant. Therefore, the characters were divided so that the first card was punched for the floral data, the second card was punched for the vegetative data. The first column of each card was used for the card identification, then the next three columns were used for the alphameric (containing both letters and numbers) specimen identification (collection number). An example of a data card is shown in Figure 3 on the following page.

Before the computer could be used to produce the desired results a program had to be available. Such a program is originally written in FORTRAN by a programmer. This is punched on a series of cards which forms the SOURCE DECK. Normally, the computer utilizes the SOURCE DECK and translates this into a series of cards, the OBJECT DECK, written in binary code. While the program can be run directly from a SOURCE DECK, the OBJECT



A = Card Identification B = Specimen Identification

1-22 = character values

FIG. 3. IBM data card.

DECK is more compact and involves less computer time. Following a program deck is a series of cards specifying the characteristics of the data. These are the parameter cards.

The INPUT required for the TAL program is shown in Figure 4. In this diagram the title of each card or set of cards is shown in the upper right corner. The information on the card is shown in the upper left corner, and below the information the starting column is marked. For example, on the K, M, NO, IPTAL card which can be located by the title in the upper right corner of set five, the K data has three integers (I3 format) starting in column one, the M information has three integers starting in column four, the NO information has three integers starting in column seven, and the IPTAL has three integers starting in column ten. All the information punched on parameter cards three, five, and six is in the I3 format which means that each of these parameters requires three integers.

An explanation of each set in the TAL INPUT using the values of this study is as follows: 1) the OBJECT DECK, which has been previously discussed, tells the computer what it is to do step by step with the following cards; 2) the ENTRY card tells the computer to start reading the succeeding cards; 3) the NSET card records the number of sets of data, i.e. the number of times the following cards are to be processed (NSET = 1); 4) the TITLE card bears the title of the program (*CARDUUS* TAL); 5) the K, M, NO, IPTAL card is punched for the number of desired frequency distributions (K = 41),

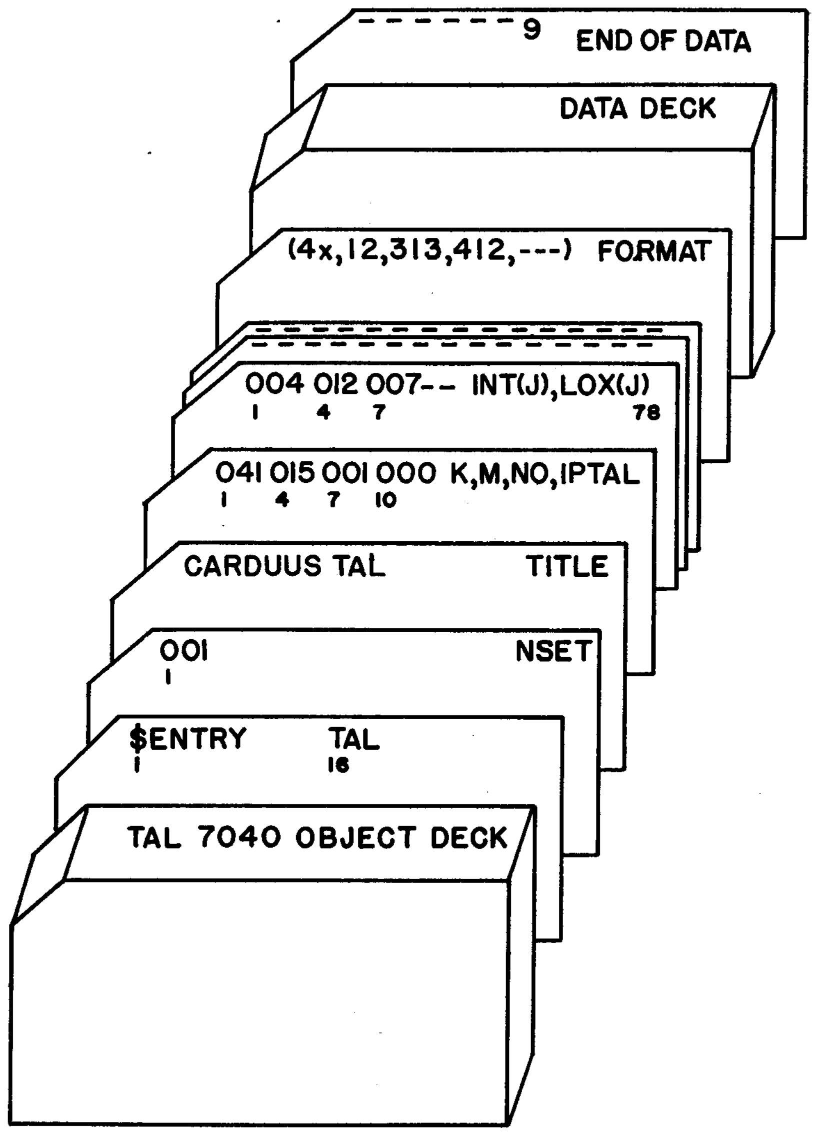


FIG. 4. The INPUT required for the TAL program.

TABLE 3

Character Frequency Distributions and Standard Deviations Based on 100 Specimens

	Character																				
Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1	1	1	1	1	1	2	2	5	3	2	2	2	4	2	2	1	2	5	2	2
2	4	1	0	1	0	1	5	3	14	1	2	1	1	0	2	1	5	2	5	0	9
3	7	2	0	2	1	3	12	8	16	2	2	1	0	3	0	7	10	2	11	3	22
4	12	1	5	3	0	5	12	17	13	4	4	3	1	5	2	13	14	3	11	5	23
5	15	2	0	3	3	18	10	24	16	6	11	7	4	7	2	7	21	15	23	10	22
6	11	1	0	2	3	6	11	16	10	15	23	2	6	13	7	16	14	16	13	11	10
7	15	4	4	8	13	15	18	15	7	14	23	6	5	19	15	18	19	16	8	12	4
8	7	6	8	10	11	18	13	5	6	8	21	20	14	16	16	13	7	11	3	14	3
9	9	9	16	13	17	13	5	3	5	14	9	18	19	9	18	9	4	13	8	18	0
10	8	17	20	16	11	7	7	0	1	13	0	13	16	10	16	7	1	7	4	8	1
11	4	14	27	14	11	5	0	0	0	5	0	11	16	8	9	2	3	7	4	6	0
12	2	22	13	13	16	2	1	2	0	4	0	8	8	3	6	2	1	2	1	2	0
13	4	11	2	5	5	1	0	0	2	6	0	2	3	2	2	1	0	0	0	3	0
14	0	4	1	5	4	0	0	1	2	2	0	4	1	1	2	2	0	3	0	3	1
15	1	2	0	1	0	0	0	0	0	0	0	2	4	0	1	0	0	1	1	0	0
s.d.	.11	5.4	2.6	3.1	2.1	.07	.15	.17	.24	6.9	5.2	3.1	3.6	1.6	0.8	.08	0.6	0.8	2.1	1.6	.27

TABLE 3 *(continued)*

	Character																			
Class	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	45	6	3	2	3	6	2	1	2	4	1	2	1	3	6	7	1	3	4	1
2	36	12	7	1	5	5	2	0	8	13	2	5	2	3	8	13	1	6	21	3
3	13	10	7	4	3	3	6	1	13	14	8	11	6	3	9	24	2	9	19	21
4	3	14	11	13	14	8	5	3	16	9	9	10	4	6	14	18	18	11	14	22
5	0	18	19	11	9	14	15	2	10	20	9	10	12	7	8	13	8	12	14	14
6	0	9	9	19	9	16	14	6	11	16	17	11	9	18	15	12	21	13	12	15
7	1	9	10	13	12	24	19	6	14	6	11	18	14	13	10	2	14	9	5	6
8	0	9	9	12	8	8	5	13	10	4	8	7	19	13	10	6	4	15	3	10
9	1	2	11	2	8	8	7	19	5	6	7	12	12	17	7	1	12	5	3	2
10	0	4	5	13	9	6	8	21	6	5	11	2	12	5	1	0	2	5	0	0
11	0	2	4	3	9	0	6	11	1	1	9	5	5	5	5	0	5	3	1	1
12	0	3	2	5	2	0	4	9	1	0	3	2	1	5	2	0	5	5	0	1
13	0	1	2	0	1	0	4	4	1	0	4	3	1	1	1	0	1	0	0	0
14	0	0	0	0	4	0	2	1	1	1	0	0	1	0	1	0	2	0	0	0
15	1	0	1	1	4	1	1	2	1	0	1	1	1	1	0	1	0	1	1	1
s.d.	8.2	5.0	12	4.5	12	5.4	9.8	4.3	8.8	3.2	3.9	3.0	2.9	1.6	5.9	4.3	2.6	2.8	2.1	.29

the number of classes (m = 15), the "no score option" which is one (NO = 1) if the blanks and zeros are legitimate scores, or zero (NO = 0) if they are not, and the indicator for either the inclusion or exclusion of the percentage distribution which is one if desired or zero if not (IPTAL = 0); 6) the INT(J)–LOX(J) set of cards records without a break, first the size of the class interval for each variable (INT(J)), and then the minimum value for each variable (LOX(J)); 7) the FORMAT card describes the location of the variables (4x,I2,3I3,4I2, . . .); 8) the DATA DECK contains the data collected from the 100 plants; 9) the END OF DATA set which has as many cards as there are cards *per specimen* (2) has a nine (9) punched on the second card in the column following the last column of data. This is the basic INPUT, but depending upon the requirements of the computer center, several cards may precede this series, for center administrative functions (e.g. who to charge, etc.).

The variation in each character was consistently divided into fifteen classes. While any number could have been chosen, the fifteen classes used in this program were selected for three reasons. First, the classes containing one-fifteenth of the total variation of a character would give a reasonable degree of precision to the frequency distributions. Second, the analysis of the characters as a group would be simplified using a common base. Third, the conversion of the range of variation into the five classes necessary for the hybrid index might be simplified by using a multiple of five. The percentage distributions were considered unnecessary, since the frequency distributions adequately showed the tendencies of the character variation toward normal or bimodal distributions.

The information "printed out" by the computer, the OUTPUT, consisted of six computations: 1) the frequency distributions for each character; 2) a list of the values beyond the range of the distribution specified, the character with which the values are associated, and the interval in which they could fall if the number of classes was extended; 3) the grand total for each of the frequency distributions; 4) the mean; 5) the variance; and 6) the standard deviation for each character.

The computations of primary concern were the frequency distributions shown in Table 3. Also included in this table are the standard deviations for each character which are shown beneath the last class. Most of the character variation showed a tendency toward normal distribution, with a skewness to either the right or left. Several of the distributions had no cases in the fifteenth class, and a few of them had no cases in the tenth or eleventh to the fifteenth

class. The explanation for this was simply that frequently the range of character variation was not evenly divisible by fifteen; the class size had to be increased and hence the number of empty classes increased. The peduncle length (character 22) had the least tendency toward normal distribution; all but three cases fell into the first four classes. Although several of the distributions were broken by the lack of cases in a specific class, no bimodality was found in any of the character distributions which could not, at least tentatively, be explained by sample size.

Since the characters, excluding peduncle length, showed a tendency for normal distribution, it was necessary to determine whether the population represented a highly variable species or whether it was the result of introgressive hybridization. A test for the correlation of characters was necessary to determine which of the two alternatives existed in Nebraska.

The conventional method in checking for plant character correlations is the preparation of scatter diagrams. This is a tedious process since each character should be checked against all others. To do a thorough job, 820 scatter diagrams would be necessary, and it would take months to complete this project. Once again, it was found that the computer could be beneficial through a correlation coefficient program (CORCO) prepared by Dale Nelson. This program, which is set up for the IBM 7040 computer, computes the Pearson's correlation coefficients, the sums, the sums of squares, the means, and the standard deviations for up to 142 variables in a set.

The INPUT required for the CORCO program is shown in Figure 5. The CORCO INPUT consists of six sets of cards which are as follows: 1) the OBJECT DECK; 2) the ENTRY card; 3) the NSET card (N = 1); 4) the FORMAT card (4x,I2,3I3,4I2, . . .); 5) the TITLE, N, M, IPAR1 card on which is punched the TITLE (*CARDUUS*), the number of variable (N = 41), the number of specimens (M = 100), and the correlation coefficient indicator (IPAR1 = 1); and 6) the DATA DECK which is the same as that used in the TAL program.

The CORCO OUTPUT consists primarily of a table of the correlation coefficients (Table 4). The coefficient values ranged from 0.000 to 1.000, some being negatively correlated. The 1.000 coefficient values were the result of a character being correlated against itself and were thus excluded from further analysis. Excluding the 1.000 coefficients there were 820 coefficients tabulated.

It was necessary to determine systematically the acceptability of each character based on correlation coefficients. Instead of testing

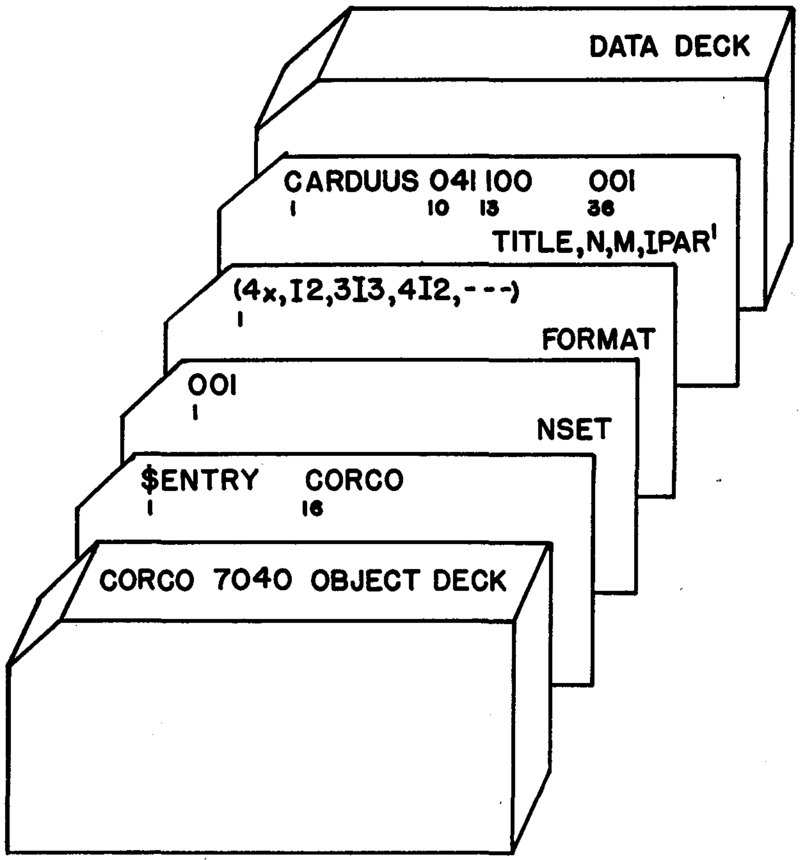


FIG. 5. The INPUT required for the CORCO program.

character correlations by using the conventional scatter diagrams, a system was devised in which correlation coefficients replaced scatter diagrams. For example, in the conventional method in the case of four characters, scatter diagrams would be made to check character 1 against 2, character 2 against 3, character 3 against 4, and character 4 against 1. An interwoven arrangement is thereby formed by this checking of each character against two other characters, By replacing the scatter diagrams with the correlation coefficients, a comparable type of system is formed.

The method of measuring a character can also be evaluated at this point. Occasionally a character may be measured in more than one way, and the best method may be selected while the others are discarded. For example, in many cases it was not known whether a

Table 4. Correlation coefficients based on 100 specimens.

Character Identification Number

	1*	2*	3*	4*	5*	6	7	8	9	10*	11*	12*	13*	14*	15*	16*	17*	18*	19	20
1*	1.000																			
2*	-0.285	1.000																		
3*	-0.219	0.944	1.000																	
4*	-0.324	0.958	0.812	1.000																
5*	-0.172	0.755	0.726	0.707	1.000															
6*	0.101	0.518	0.554	0.428	0.879	1.000														
7	0.040	0.588	0.531	0.572	0.903	0.958	1.000													
8	0.202	0.347	0.475	0.185	0.730	0.933	0.810	1.000												
9	0.225	0.393	0.624	0.145	0.367	0.577	0.389	0.742	1.000											
10*	-0.542	0.771	0.750	0.721	0.610	0.393	0.428	0.267	0.300	1.000										
11*	-0.325	0.912	0.877	0.866	0.755	0.531	0.581	0.372	0.369	0.783	1.000									
12*	-0.640	0.177	0.160	0.190	0.152	-0.125	-0.104	-0.176	-0.222	0.366	0.222	1.000								
13*	-0.641	0.198	0.181	0.211	0.175	-0.119	-0.096	-0.175	-0.226	0.387	0.260	0.982	1.000							
14*	-0.800	0.272	0.194	0.325	0.168	-0.140	-0.069	-0.249	-0.307	0.521	0.303	0.720	0.727	1.000						
15*	-0.429	0.237	0.178	0.280	0.156	-0.147	-0.084	-0.245	-0.306	0.366	0.251	0.620	0.648	0.853	1.000					
16*	-0.575	0.273	0.184	0.331	0.142	-0.081	0.000	-0.202	-0.243	0.433	0.277	0.155	0.194	0.775	0.703	1.000				
17*	-0.581	0.252	0.171	0.304	0.105	-0.103	-0.028	-0.212	-0.227	0.412	0.242	0.177	0.184	0.782	0.688	0.968	1.000			
18*	-0.339	0.241	0.175	0.284	0.220	-0.046	0.027	-0.133	-0.225	0.239	0.200	0.520	0.552	0.432	0.476	0.206	0.177	1.000		
19	-0.320	0.153	0.057	0.228	0.174	0.015	0.094	-0.081	-0.243	0.172	0.148	0.308	0.339	0.349	0.324	0.249	0.174	0.237	1.000	
20	-0.270	0.188	0.108	0.241	0.211	0.070	0.131	-0.004	-0.160	0.163	0.155	0.239	0.246	0.253	0.174	0.150	0.090	0.197	0.754	1.000
21	0.205	-0.071	-0.071	-0.072	0.023	0.131	0.114	0.161	0.082	-0.223	-0.079	-0.205	-0.251	-0.316	-0.393	-0.327	-0.318	-0.130	-0.082	0.480
22	0.013	0.164	0.141	0.170	0.086	0.012	0.046	-0.022	0.006	0.108	0.205	0.132	0.131	0.040	0.110	-0.034	-0.007	0.117	0.031	0.049
23*	-0.437	-0.093	-0.139	-0.033	0.049	-0.098	-0.058	-0.140	-0.334	0.139	-0.045	0.383	0.409	0.458	0.399	0.338	0.303	0.333	0.392	0.312
24*	-0.441	-0.090	-0.145	-0.027	0.013	-0.148	-0.106	-0.185	-0.362	0.171	-0.063	0.406	0.423	0.505	0.454	0.373	0.348	0.317	0.383	0.280
25	-0.045	0.017	0.027	-0.007	-0.055	-0.068	-0.084	-0.018	0.036	0.086	-0.009	0.033	0.037	0.127	0.096	0.117	0.109	-0.010	0.054	0.044
26*	-0.503	-0.120	-0.188	-0.044	-0.027	-0.181	-0.131	-0.219	-0.394	0.157	-0.082	0.408	0.422	0.565	0.471	0.438	0.407	0.323	0.418	0.356
27	-0.306	-0.018	-0.053	0.004	-0.085	-0.160	-0.141	-0.139	-0.126	0.160	0.002	0.150	0.155	0.371	0.249	0.348	0.320	0.130	0.219	0.268
28*	-0.454	-0.089	-0.128	-0.040	-0.006	-0.145	-0.116	-0.171	-0.319	0.184	-0.043	0.351	0.370	0.491	0.410	0.395	0.370	0.288	0.326	0.289
29	-0.165	0.003	0.014	-0.015	-0.090	-0.123	-0.137	-0.075	0.010	0.143	0.011	0.054	0.062	0.212	0.126	0.212	0.196	0.039	0.061	0.171
30*	-0.407	-0.134	-0.192	-0.065	0.013	-0.127	-0.081	-0.161	-0.370	0.090	-0.127	0.456	0.472	0.477	0.439	0.277	0.260	0.404	0.411	0.296
31	-0.105	-0.054	-0.081	-0.042	-0.034	-0.061	-0.043	-0.024	-0.075	-0.013	-0.132	0.171	0.180	0.180	0.153	0.060	0.055	0.267	0.209	0.124
32*	-0.176	-0.058	-0.113	0.015	0.033	-0.107	-0.046	-0.154	-0.336	0.038	-0.092	0.342	0.348	0.270	0.329	0.110	0.094	0.264	0.330	0.128
33	0.198	0.026	0.015	0.021	0.036	0.061	0.065	0.066	0.029	-0.093	-0.056	-0.007	-0.015	-0.123	-0.025	-0.156	-0.146	-0.021	-0.020	-0.165
34*	-0.305	0.032	0.026	0.038	-0.066	-0.126	-0.128	-0.125	-0.051	0.233	0.128	0.091	0.095	0.297	0.162	0.335	0.310	0.002	0.082	0.195
35*	-0.390	-0.045	-0.094	0.002	-0.084	-0.174	-0.138	-0.183	-0.191	0.150	0.100	0.197	0.201	0.397	0.255	0.357	0.330	0.168	0.249	0.332
36*	-0.274	-0.105	-0.143	-0.064	-0.052	-0.086	-0.064	-0.078	-0.168	0.088	-0.088	0.222	0.235	0.313	0.240	0.241	0.219	0.277	0.246	0.158
37	0.091	-0.107	-0.094	-0.125	-0.136	-0.015	-0.040	0.065	0.127	-0.064	-0.119	-0.104	-0.114	-0.066	-0.125	-0.050	-0.050	-0.030	-0.078	-0.096
38	-0.016	0.040	0.068	0.005	0.153	0.117	0.105	0.138	0.057	0.004	0.057	0.115	0.118	-0.032	-0.002	-0.122	-0.097	0.124	0.037	-0.083
39*	-0.314	-0.061	-0.109	-0.014	0.045	-0.054	-0.025	-0.079	-0.242	0.136	-0.061	0.430	0.440	0.372	0.321	0.149	0.136	0.362	0.402	0.312
40	0.098	-0.009	0.002	-0.032	0.002	0.074	0.051	0.106	0.107	-0.023	-0.052	0.059	0.054	-0.057	-0.067	-0.156	-0.148	0.086	0.005	-0.014
41*	0.056	0.026	0.021	0.030	0.148	0.161	0.165	0.114	-0.027	-0.015	0.038	0.089	0.089	-0.034	0.008	-0.121	-0.100	0.063	0.047	-0.024

	21	22	23*	24*	25	26*	27	28*	29	30*	31	32*	33	34*	35*	36*	37	38	39*	40	41*
21	1.000																				
22	0.038	1.000																			
23*	-0.192	-0.115	1.000																		
24*	-0.265	-0.072	0.894	1.000																	
25	-0.084	-0.327	-0.010	0.161	1.000																
26*	-0.155	-0.044	0.839	0.917	0.145	1.000															
27	0.057	-0.156	0.193	0.316	0.677	0.549	1.000														
28*	-0.178	-0.049	0.857	0.945	0.120	0.936	0.397	1.000													
29	0.068	-0.229	0.173	0.301	0.758	0.404	0.808	0.446	1.000												
30*	-0.201	0.007	0.868	0.891	0.002	0.874	0.263	0.855	0.193	1.000											
31	-0.056	-0.132	0.195	0.203	0.557	0.281	0.527	0.181	0.470	0.429	1.000										
32*	-0.339	-0.089	0.532	0.637	0.197	0.422	-0.019	0.363	-0.169	0.528	0.161	1.000									
33	-0.196	-0.156	-0.277	-0.203	0.424	-0.360	-0.121	-0.454	-0.245	-0.266	0.199	0.528	1.000								
34*	0.098	-0.071	0.173	0.304	0.354	0.474	0.730	0.408	0.590	0.078	-0.105	-0.078	-0.317	1.000							
35*	0.160	0.055	0.301	0.298	0.071	0.625	0.771	0.446	0.469	0.370	0.258	-0.202	-0.548	0.681	1.000						
36*	-0.140	-0.149	0.603	0.624	0.224	0.659	0.391	0.646	0.367	0.571	0.289	0.298	-0.164	0.288	0.351	1.000					
37	0.037	-0.176	-0.088	-0.028	0.397	0.043	0.352	0.012	0.370	-0.065	0.286	-0.080	0.096	0.203	0.142	0.689	1.000				
38	-0.190	0.023	0.053	-0.069	-0.064	-0.205	-0.322	-0.225	-0.365	-0.056	-0.000	0.309	0.412	-0.379	-0.410	-0.163	-0.183	1.000			
39*	-0.151	-0.020	0.627	0.603	0.150	0.543	0.188	0.505	0.102	0.603	0.307	0.553	0.082	0.044	0.126	0.704	0.347	0.276	1.000		
40	0.020	-0.028	-0.253	-0.256	0.291	-0.266	0.046	-0.336	-0.022	-0.221	0.268	0.080	0.483	-0.171	-0.212	0.252	0.609	0.344	0.535	1.000	
41*	-0.068	-0.185	-0.083	-0.198	-0.047	-0.295	-0.304	-0.357	-0.373	-0.131	0.041	0.201	0.432	-0.393	-0.396	-0.343	-0.304	0.612	0.196	0.332	1.000

* Characters used in evaluating 282 specimens.

Character Identification Number

particular leaf selected for measurement had been located near the base or near the tip of the plant, and since variation depending on the leaf location on the plant might obscure the inherent genetic variation, all the leaf lengths were arbitrarily converted to 10 cm, and this conversion factor became the correction factor which was applied to other leaf characters. Hence, if a leaf were actually 20 cm long, converting this length to 10 cm produced a correction factor of 0.5, then the other measurements of that leaf were reduced by 0.5. A comparison of the correlation coefficients of the original leaf values with those of the corrected values, showed that the original values tended to have higher correlations with other characters than did the corrected values. Therefore, the corrected character values (25, 27, 29, 31, 33, 35, 37, 40, see Table 2) were discarded.

Another character, peduncle length, was also eliminated. It was discarded on the basis that only three of its forty correlation coefficients were significant (0.195 or greater) at the 0.05 level (Snedecor, 1946, p. 149).

With the remaining 32 characters, a system was devised in which the characters were matched by correlation coefficients of 0.195 or greater with at least three other characters. Throughout the procedure checks were made so that no character was used more than once in the system. The results of the procedure are shown in Figure 6, and the steps which were involved are as follows: 1) to select the highest correlation coefficient (0.982); 2) to place one of the characters (character 12) in the left hand column; 3) to place the other character (character 13) in the next column directly across from the first character; 4) to select the next high coefficient (0.727) involving the second character; 5) to place the new character (14) in the third column directly across from the first two characters; 6) to select the highest correlation coefficient (0.853) involving the third character (14); 7) to place the other character (15) in the fourth column directly across from the others; 8) to select the third high coefficient (–0.640) involving the first character (12); 9) to place the new character (1) in the upper portion of the second column; 10) to check coefficient value (–0.641) of the second character (13) with the new character (1); 11) to select a character (10) having a high coefficient with the character (1) in the upper portion and the character (14) in the third column; 12) to place this character (10) in the upper portion of the third column. These steps were continued until the upper portion of the diagram was filled in. As each character was added to the system, it was checked by its correlation coefficients against all the other characters with which it was matched. For

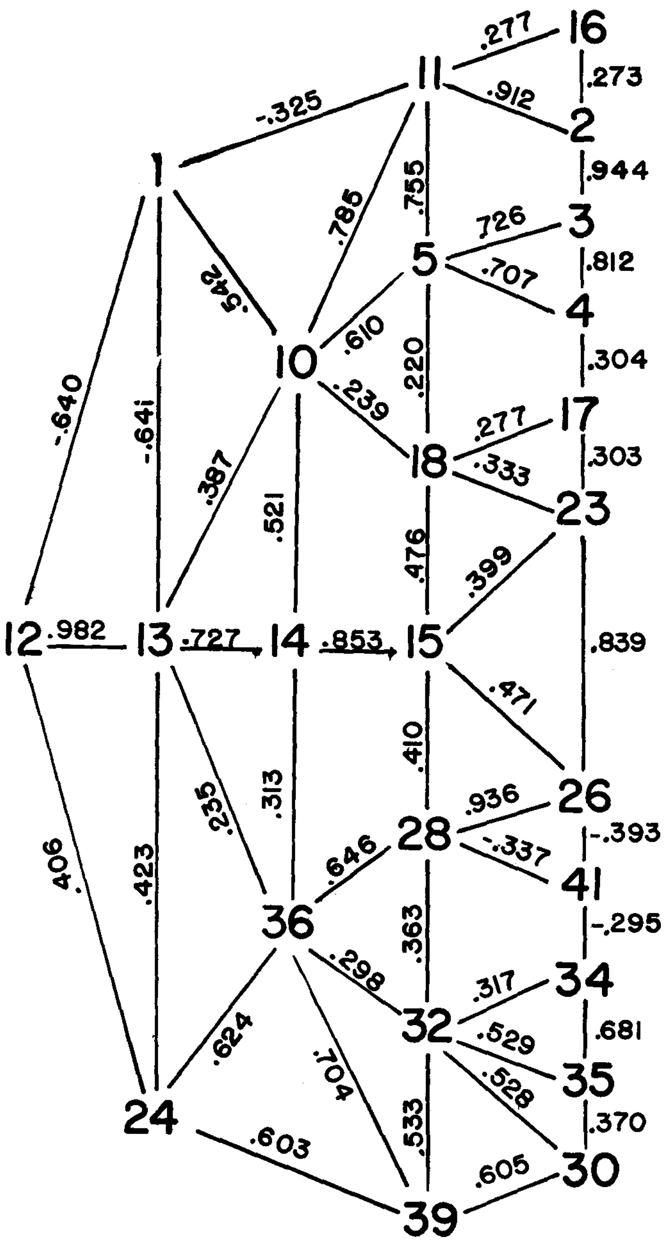


Fig. 6. CORCO analysis maze.

example, although character 10 was matched with both character 1 and 14 before it was placed in the system, it was later checked against character 13, 11, 5 and 18 to see if any of the coefficients were below the 0.195 level. If one of the correlation coefficients had had a value below 0.195, then either character 10 or the other character would have been removed from the system. The lower portion of the diagram was completed in the same manner as the upper portion.

As a result of this systematic matching of characters by correlation coefficients, twenty-five characters were deemed acceptable while seven were considered unacceptable.

The Final Population Study

Of the 302 specimens collected, 282 had all of the required characters present. These 282 were measured in the manner shown in Plates 1 and 2. The data collected from each specimen were transferred to a single IBM punch card in the same manner as in the preliminary study, except that it was not necessary to use the first column for card identification.

These data were processed through the TAL program resulting in the frequency distributions and standard deviations for each of the twenty-five characters shown in Table 5. Plates 3, 4, 5, and 6 show histograms constructed from the TAL OUTPUT. There is a tendency toward a normal distribution in the case of each character as is indicated in both the table and the histograms. Therefore, all the characters were tested for correlations by using the CORCO program. The resulting OUTPUT consisted of 300 correlation coefficients which ranged from 0.002 to 0.952, excluding the 1.000 values (see Table 7).

During the course of the analysis, a new system was devised to determine the acceptability of characters based on the consistency of the correlations. Since the correlation of any two characters could be due to chance and since the correlation of more than two characters with each other reduces the probability of correlation by chance, it was felt that consistency of correlations should be of greater significance than the correlations coefficient values alone. For example, if there were a 5% possibility that a correlation coefficient of 0.113 between characters A and B is due to mere chance according to Snedecor (p. 149), and if there were a 1% possibility that the 0.148 coefficient between characters A and C is due to chance, then the probability of the *three* characters being correlated through chance is reduced to 0.05%. The addition of each character that was con-

sistent within the system reduces the probability of correlation due to chance.

On this basis, the highest correlation values were used as the starting point to develop a consistent system. These correlation coefficients and the characters involved were as follows:

Characters	17 and 19	0.952
	11 and 13	0.933
	18 and 19	0.919
	17 and 18	0.900
	16 and 17	0.900
	3 and 4	0.886
	16 and 19	0.871
	7 and 8	0.871
	16 and 20	0.861
	11 and 12	0.849
	17 and 20	0.841
	5 and 6	0.837
	16 and 18	0.836
	5 and 10	–0.830
	2 and 11	0.809

From the above it can be seen that both positive and negative correlations were involved. It was relatively simple to set up two

Plate 1. Figures showing how the character measurements were obtained.

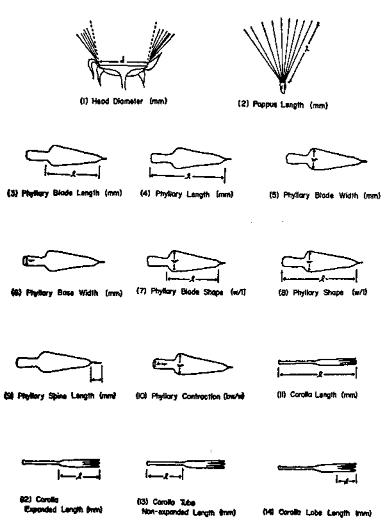


Plate 2. Figures showing how the character measurements were obtained.

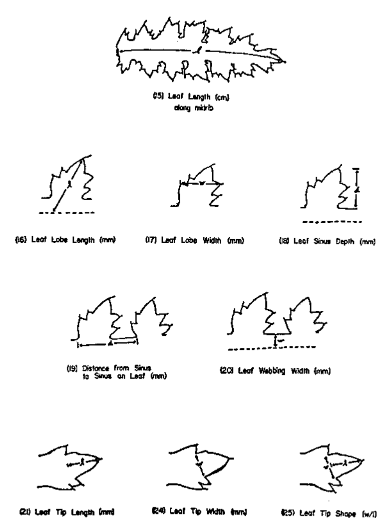


TABLE 5

Character Frequency Distributions and Standard Deviations Based on 282 Specimens

	Character																								
Class	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	2	6	3	4	9	4	0	4	5	1	3	1	1	1	5	8	3	6	3	2	1	0	14	3	4
2	3	8	9	4	3	5	4	16	2	6	3	1	8	0	13	12	15	9	7	10	7	3	27	16	10
3	9	8	6	1	13	1	7	32	7	12	5	5	3	1	36	19	18	22	23	16	27	14	28	35	28
4	4	13	17	10	26	3	19	50	8	24	4	5	2	3	52	47	45	54	38	25	23	28	40	55	31
5	6	38	18	9	36	7	30	61	31	46	9	6	11	17	51	42	41	36	53	40	37	32	30	62	60
6	19	66	27	25	54	23	30	50	42	50	5	17	7	8	39	38	30	46	39	46	27	48	35	43	53
7	32	79	48	32	53	37	37	33	40	41	14	23	10	33	29	29	26	31	38	40	45	62	32	27	41
8	45	44	46	45	35	41	50	18	46	27	20	60	24	39	26	23	35	24	42	25	39	48	24	14	31
9	31	19	47	51	25	56	36	11	35	32	28	75	23	49	17	29	22	25	17	16	25	28	18	18	17
10	34	0	33	38	15	51	27	3	31	24	43	65	42	51	5	11	22	7	7	28	27	12	9	3	4
11	30	0	14	24	9	25	14	0	18	9	59	17	31	38	4	10	4	12	5	16	7	4	12	2	1
12	33	0	9	24	2	19	9	4	5	8	48	7	41	29	4	6	8	7	5	4	5	1	2	1	0
13	15	0	4	10	1	7	13	0	4	2	24	0	45	5	0	3	8	1	1	7	6	0	3	1	1
14	9	0	0	3	1	1	4	0	4	0	13	0	20	7	0	2	4	1	3	4	2	0	5	1	1
15	10	0	1	1	0	2	2	0	4	0	4	0	5	0	1	1	0	1	1	3	3	2	1	0	0
s.d.	5.8	3.5	3.3	4.6	1.6¾	0.7	.08	.06	0.7	.11	3.3	1.5	2.2	1.3	5.4	4.4	11	11	9.6	3.7	3.3	1.6	5.7	2.8	.10

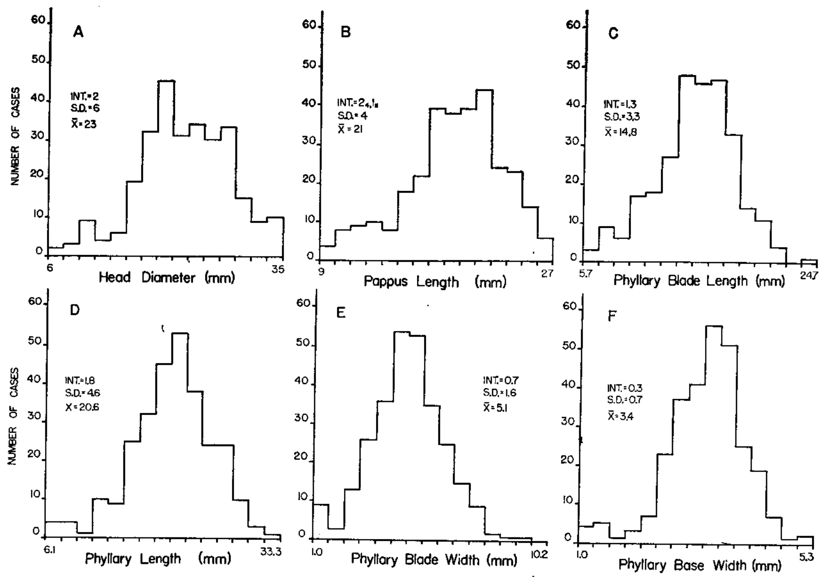


Plate 3. Frequency distribution of characters used in the hybrid index.

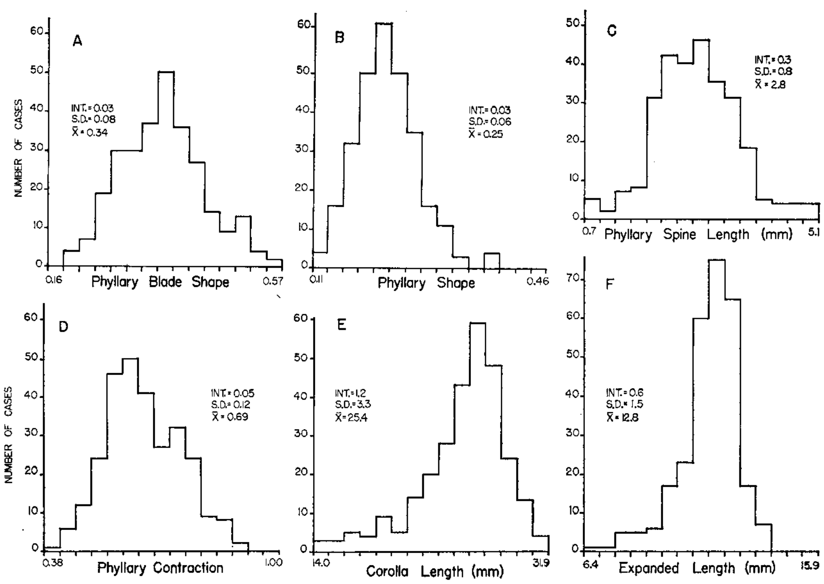


Plate 4. Frequency distribution of characters used in the hybrid index.

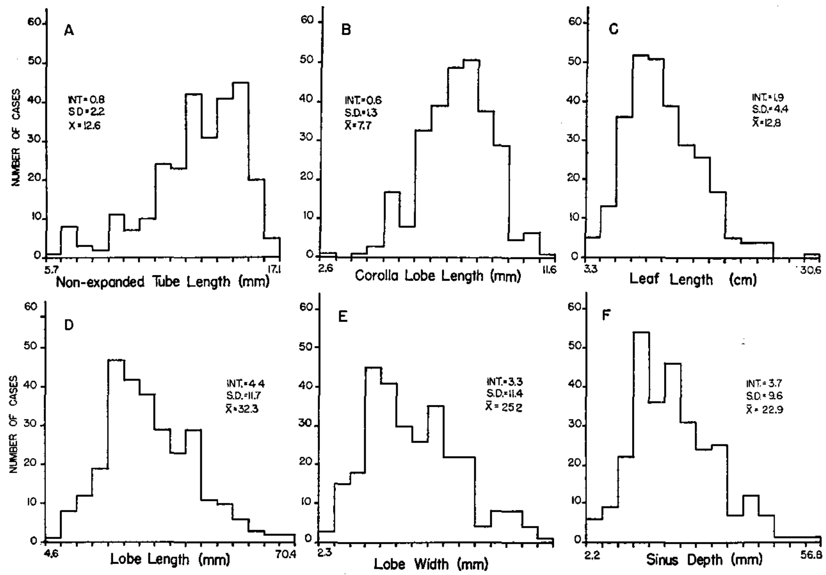


Plate 5. Frequency distribution of characters used in the hybrid index.

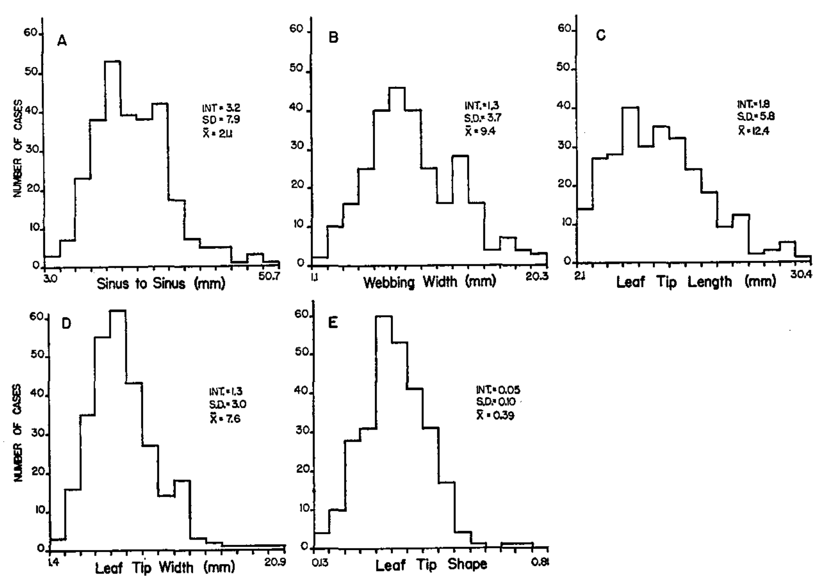


Plate 6. Frequency distribution of characters used in the hybrid index.

series of characters, positive and negative. Of the sixteen characters listed above all but character 10 were positive. To this list the other nine characters were added (see Table 6). To set up a system of consistent correlations, each positive character had to be positively correlated with every other positive character and negatively correlated with every negative character. In addition, each negative character had to be positively correlated with every other negative character.

Inconsistencies were noted in which negative correlation values occurred between two positive characters. These were denoted in the table by lines connecting the two characters. This would also hold true if negative correlation values occurred between two negative characters, or if positive correlation values occurred between a positive and a negative character. To achieve consistency, characters 20, 21, 22, and 23, which showed inconsistencies, were checked. Character 22, which had inconsistencies with characters 20 and 21, was eliminated because its correlation coefficient values tended to be lower than those of character 21, which also had two inconsistencies. The remaining inconsistency was between characters 21 and 23. In this case, character 23 was eliminated because its correlation coefficients were as a whole lower than those of character 21 which was retained in the system.

TABLE 6

SYSTEM OF CONSISTENT CORRELATIONS

Positive characters				Negative characters
1	7	14	20	
2	8	15	21	
3	9	16	22	
4	11	17	23	10
5	12	18	24	
6	13	19	25	

This procedure resulted in the elimination of two characters, but the remaining twenty-three characters showed a consistent system of correlation which had an extremely high level of significance.

A comparison of correlation coefficients with scatter diagrams was made and the diagrams are shown in Plates 7, 8, and 9. The fifteen examples give some indication as to the meaning of correlation coefficients of less than 0.300 in relation to the distribution of the correlations in a scatter diagram.

The only logical explanation for the consistent correlation of the twenty-three characters was to postulate hybridization, with the extremes for each character originating in two different parental

types. Further evidence for the postulation, especially with respect to the type of population sampled, was obtained by using the hybrid index.

The steps for setting up the hybrid index were: 1) the determination of the range of variation for each character; 2) the division of this range of variation into five classes; 3) the assignment of an arbitrary hybrid value of zero (0) to one extreme and a hybrid value of four (4) to the other (see Table 8); and 4) the totalling of the twenty-three hybrid values for each specimen to obtain the hybrid index for the specimen.

Each of these steps was taken in the analysis of the 282 specimens using twenty-three characters. Some adjustments were necessary to balance the variation around the central hybrid value of two. Since the character "phyllary contraction" was negatively correlated, it was necessary to assign the hybrid value of zero to the maximum character measurement and the maximum hybrid value to the minimum character measurement.

With twenty-three characters, the possible range of the hybrid indices was from 0 (*C. acanthoides*) to 92 (*C. nutans*); the actual range was from 3 to 77 (see Plate 10, Figure A). The histogram shows a general tendency toward normality which indicates that the population is essentially a hybrid swarm with only one near parental type represented.

Table 7. Correlation coefficients based on 282 specimens.

Character Identification Number (columns); Character Identification Number (rows)

	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13	14	15	16	17	18	19	20	21	22	23	24	25
1*	1.000																								
2*	0.679	1.000																							
3*	0.592	0.513	1.000																						
4*	0.561	0.504	0.886	1.000																					
5*	0.716	0.572	0.710	0.681	1.000																				
6*	0.593	0.519	0.547	0.561	0.837	1.000																			
7*	0.467	0.366	0.052	0.134	0.710	0.699	1.000																		
8*	0.472	0.348	0.138	0.002	0.708	0.647	0.871	1.000																	
9*	0.308	0.314	0.521	0.503	0.358	0.344	0.051	0.054	1.000																
10*	-0.662	-0.524	-0.694	-0.630	-0.830	-0.452	-0.495	-0.534	-0.337	1.000															
11*	0.667	0.809	0.540	0.528	0.581	0.564	0.365	0.353	0.404	-0.509	1.000														
12*	0.597	0.748	0.507	0.515	0.523	0.550	0.318	0.288	0.353	-0.422	0.849	1.000													
13*	0.604	0.718	0.477	0.456	0.533	0.492	0.345	0.343	0.378	-0.488	0.933	0.609	1.000												
14*	0.489	0.594	0.360	0.333	0.392	0.383	0.247	0.254	0.276	-0.352	0.666	0.663	0.550	1.000											
15*	0.512	0.317	0.431	0.393	0.466	0.381	0.261	0.274	0.240	-0.445	0.337	0.271	0.330	0.319	1.000										
16*	0.549	0.319	0.434	0.403	0.487	0.377	0.282	0.288	0.256	-0.467	0.344	0.268	0.344	0.316	0.900	1.000									
17*	0.517	0.278	0.419	0.416	0.511	0.378	0.302	0.290	0.242	-0.488	0.295	0.223	0.299	0.266	0.836	0.900	1.000								
18*	0.538	0.303	0.390	0.377	0.473	0.362	0.299	0.290	0.206	-0.449	0.312	0.258	0.302	0.286	0.871	0.952	0.919	1.000							
19*	0.437	0.218	0.447	0.401	0.448	0.355	0.203	0.230	0.284	-0.432	0.282	0.207	0.291	0.236	0.861	0.841	0.783	0.792	1.000						
20*	0.328	0.227	0.351	0.315	0.319	0.277	0.134	0.142	0.263	-0.297	0.267	0.177	0.290	0.237	0.580	0.669	0.451	0.437	0.581	1.000					
21	0.298	0.209	0.090	0.146	0.240	0.141	0.231	0.175	0.015	-0.243	0.138	0.118	0.129	0.134	0.203	0.330	0.554	0.431	-0.027	-0.052	1.000				
22	0.227	0.104	0.152	0.188	0.296	0.190	0.209	0.192	0.068	-0.295	0.090	0.064	0.091	0.037	0.265	0.220	0.590	0.346	0.270	-0.182	0.646	1.000			
23*	0.367	0.129	0.266	0.260	0.339	0.206	0.195	0.194	0.165	-0.348	0.173	0.096	0.201	0.137	0.647	0.693	0.710	0.727	0.632	0.330	0.307	0.351	1.000		
24*	0.380	0.140	0.403	0.384	0.412	0.302	0.179	0.173	0.308	-0.377	0.220	0.163	0.235	0.182	0.619	0.641	0.588	0.560	0.671	0.582	0.062	0.159	0.673	1.000	
25*	0.284	0.118	0.144	0.176	0.284	0.155	0.209	0.190	0.112	-0.294	0.110	0.075	0.114	0.074	0.179	0.410	0.649	0.479	0.267	0.047	0.740	0.748	0.417	0.227	1.000

* Characters used in hybrid index

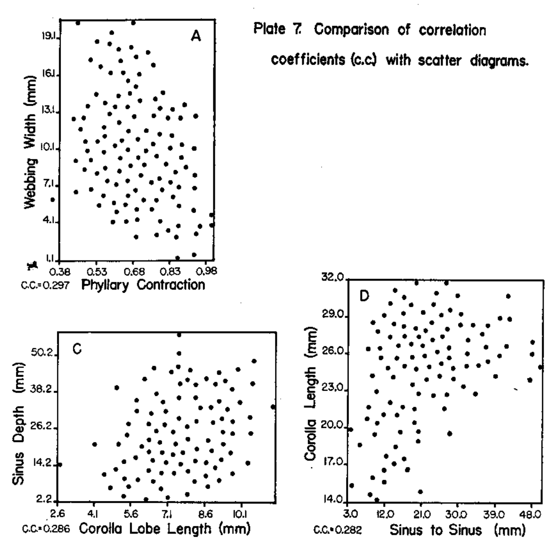


Plate 7. Comparison of correlation coefficients (c.c) with scatter diagrams.

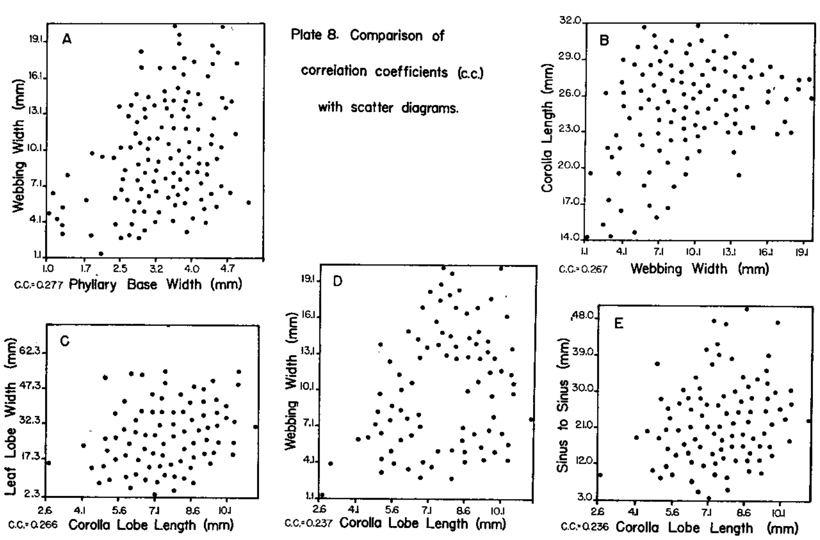


Plate 8. Comparison of correlation coefficients (c.c.) with scatter diagrams.

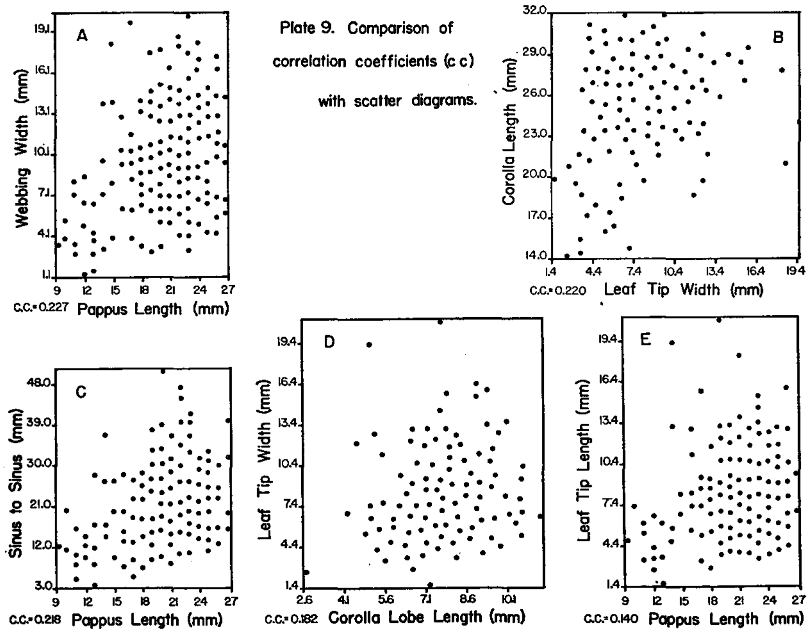


Plate 9. Comparison of correlation coefficients (c c) with scatter diagrams.

Since the procedure of setting up the hybrid index could be easily broken down into distinct steps, it was decided to attempt the production of a computer program. With the help of the computer center, such a program was designed which will herein be known as the HYBIX program. A description of the cards in the HYBIX INPUT, shown in Figure 7, using the values of this study, is as follows: 1) the SOURCE DECK which includes the GO or ENTRY card; 2) the K, M card which in I3 format K represents the number of characters (variables) and M denotes the number of specimens; 3) the LOX(J) cards which in I4 format indicate the lower integral limit of each character; 4) the INT(J) cards which in I4 format denote the size of the class interval for each character; 5) the NINT cards which in I4 format indicate the number of class intervals (this number is constant, 5); 6) the UPDOWN cards which for each positively correlated character is zero in an I4 format and for each negatively correlated character is one; 7) the FORMAT card which is similar to those of the TAL and CORCO programs except that plant identification is in A4 form; 8) the DATA DECK which was used in the other two programs; 9) the END OF DATA card which has a slash (/) in the first column and an asterisk (*) in the second column.

TABLE 8
CLASSES FOR HYBRID VALUES

		Class				
		0	1	2	3	4
Head diameter	(1)	6–11	12–17	18–23	24–29	30–35
Pappus length	(2)	9–12	13–16	17–19	20–23	24–27
Phyllary blade length	(3)	5.7–9.4	9.5–13.2	13.3–17.1	17.2–20.9	21.0–24.7
Phyllary length	(4)	6.1–11.4	11.5–16.9	17.0–22.4	22.5–27.9	28.0–33.3
Phyllary blade width	(5)	1.0–2.7	2.8–4.6	4.7–6.5	6.6–8.4	8.5–10.2
Phyllary base width	(6)	1.0–1.7	1.8–2.6	2.7–3.5	3.6–4.4	4.5–5.2
Phyllary blade shape	(7)	0.16–0.23	0.24–0.32	0.33–0.40	0.41–0.49	0.50–0.57
Phyllary shape	(8)	0.11–0.17	0.18–0.24	0.25–0.32	0.33–0.39	0.40–0.46
Phyllary spine length	(9)	0.7–1.5	1.6–2.4	2.5–3.3	3.4–4.2	4.3–5.1
Phyllary contraction	(10)	1.00–0.89	0.88–0.76	0.75–0.63	0.62–0.50	0.49–0.38
Corolla length	(11)	14.0–17.5	17.6–21.1	21.2–24.7	24.8–28.3	28.4–31.9
Corolla lobe length	(12)	2.6–4.3	4.4–6.1	6.2–8.0	8.1–9.8	9.9–11.6
Expanded length	(13)	6.4–8.2	8.3–10.1	10.2–12.1	12.2–14.0	14.1–15.9
Non-expanded length	(14)	5.7–7.9	8.0–10.2	10.3–12.5	12.6–14.8	14.9–17.1
Leaf length	(15)	3.3–8.7	8.8–14.2	14.3–19.6	19.7–25.1	25.2–30.6
Leaf lobe length	(16)	4.6–17.7	17.8–30.9	31.0–44.0	44.1–57.2	57.3–70.4
Leaf lobe width	(17)	2.3–16.5	16.6–30.8	30.9–45.2	45.3–59.5	59.6–73.8
Leaf sinus depth	(18)	2.2–13.1	13.2–24.0	24.1–34.9	35.0–45.8	45.9–56.8
Leaf sinus to sinus	(19)	3.0–12.4	12.5–22.0	22.1–31.6	31.7–41.2	41.3–50.7
Leaf webbing width	(20)	1.1–4.8	4.9–8.7	8.8–12.6	12.7–16.5	16.6–20.3
Leaf tip length	(21)	2.1–7.4	7.5–12.8	12.9–18.2	18.3–23.6	23.7–29.0
Leaf tip width	(24)	1.4–5.2	5.3–9.1	9.2–13.1	13.2–17.0	17.1–20.9
Leaf tip shape	(25)	0.13–0.25	0.26–0.39	0.40–0.54	0.55–0.68	0.69–0.81

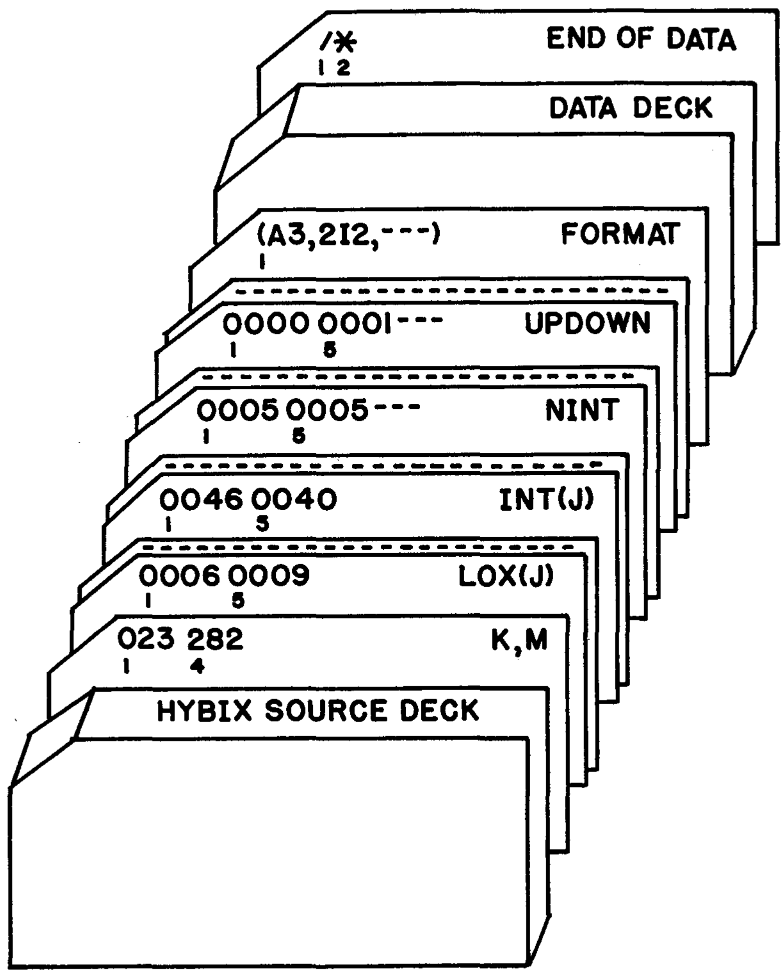


FIG. 7. The INPUT required for the HYBIX program.

The OUPUT of this program consisted of a "print out" of the hybrid values for each character and the hybrid index for each specimen. These hybrid indices were then compared with those obtained by the conventional method. In only one instance was the deviation between the two indices for the same specimen more than three points. In this exception, the deviation was six, but after verifying the measurements of this specimen it was found that many of the measurements were on the borderline between two of the hybrid values, and the computer had consistently recorded the higher value.

The hybrid indices produced by the HYBIX program were then transferred to a histogram shown in Plate 10, Figure B. The range of the hybrid indices was from 4 to 78 compared to the range of 3 to 77 in the histogram produced by the conventional method. The other statistics, such as mean and standard deviation, were the same in both procedures, although the curve produced from the HYBIX information was much smoother than that produced from the conventional method.

One advantage of using the computer involves the saving of time. The results, which were available in five minutes using HYBIX, required over forty-eight hours using conventional methods, without considering the time involved for checking mathematics.

Developmental Studies

Three stages of the life cycle of the plants formed the basis for the developmental studies: 1) seed germination; 2) seedling growth; and 3) rosette dormancy.

Seed Germination

Technically, the fruit of a composite is a cypsela, a single-seeded unilocular, bicarpellate, epigynous fruit.

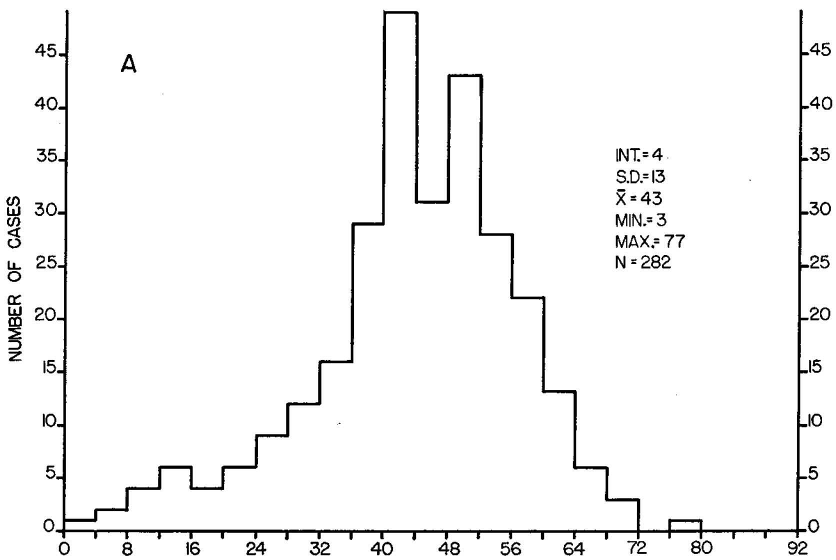
The fruit used in the germination study was from mature heads collected at various sites, and from mature heads from transplanted specimens. In the latter case, two plants were transplanted from a site south of Lincoln (collection site 15) and two from a site in north Lincoln. This latter site was not recorded as a collection site because it was a recently sodded lawn, hence the original source of the plants was unknown.

The untreated fruits were germinated under aseptic conditions on five layers of moistened filter paper in petri dishes. Thirty-two fruits from a single source were placed on the filter paper which had been stamped with thirty-two equal areas. The twenty-eight petri dishes were stored in a dark place for six days.

Although thirty-two seeds per plant was not a very large sample, it was felt that some indication of the percentage of germination might be obtained. The results of this study are shown in Table 9, indicating germination ranges from 0% to 72%.

One conclusion that could be drawn from these data was that the germination percentages as a whole were low, indicating a possibility that the seeds were of hybrid origin. But, before the meaning of a "low germination rate" could be determined, it would be necessary to know the germination rate of crosses between two plants of

Plate 10. Comparison of frequency distributions of hybrid indicies as established by conventional method (A) and by computer (B).



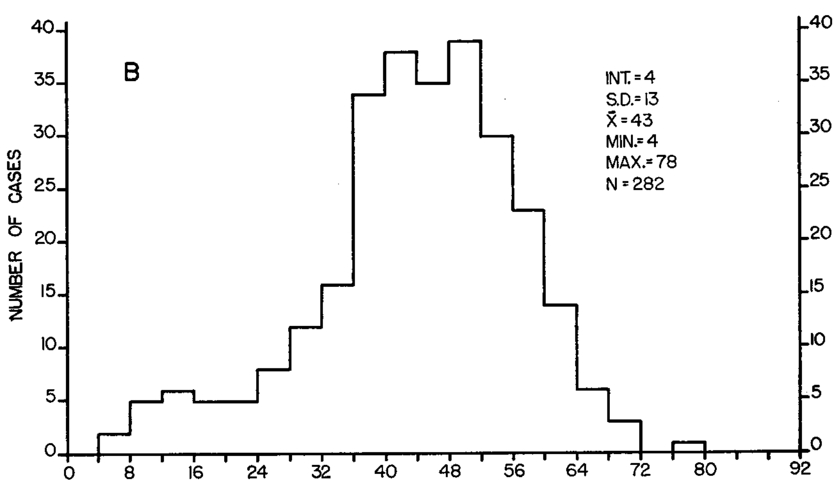


TABLE 9

PERCENTAGE GERMINATION AND HYBRID INDEX RANGE AT COLLECTION SITE OF FRUIT SOURCE

Collection Site	Remarks	No. Germinated/32	% Germination	Hybrid Index Range
3		6	19	51–64
4		16	50	48–67
6		10	31	44–53
7		16	50	27–54
8		5	16	37–63
12	dried out			
13		23	72	41–61
14		14	44	38–61
15	fasciated head	1	3	11–57
15	α x bagged only	0	0	11–57
15	α open	2	6	11–57
16		15	47	12–49
24		6	19	11–57
25		7	22	13–48
27		8	25	29–52
29		13	41	31–50
30		13	41	8–35
31		0	0	35–40
31		0	0	35–40
38		17	54	38–63
40		2	6	31–41
42		11	34	7–15
42		2	6	7–15
44		3	9	39
north Lincoln	β x bagged only	3	9	
north Lincoln	β open pollinated β x α	0	0	

one parental type, between two plants of the other parental type, and between a plant of one parental type and a plant of the other parental type which would produce an F_1 hybrid. Unfortunately, lack of time and facilities precluded such a hybridization program.

Seedling Growth

The fruits used in this treatment came from the pressed specimens which were checked for viable seeds (plump fruits with smooth coat). The fruits from a single plant were placed on moistened towelling, covered, and stored in a dark place. After one week the seedlings were planted, one per two-inch pot, in Scottsbluff, Nebraska. No germination counts were made. A week later the cotyledons were measured for length, and pictures were taken (Plate 11). All seedlings died within four weeks.

It was hoped that seedlings could be measured for various juvenile characters which might be tested for correlation with adult characters at a later date. Therefore, the procedure was repeated in the same manner but, as before, all the seedlings died in less than four weeks.

As can be seen in the photographs in Plate 11, Figures 1 and 2, the cotyledons tend to vary in blade length. This character was measured on ninety-four seedlings representing both growth attempts, and a histogram was made from the frequency distributions of cotyledon blade length (see Plate 11, Figure 3). The histogram shows a tendency toward a normal distribution, but also indicates by the skewness to the left that cotyledon blade length was influenced by the maturation process of each plant. Despite the fact that these cotyledons were measured while at the same age, it was apparent that some had matured more rapidly than others.

Since the seedlings died in less than four weeks, the only conclusion which could be made was that seedling characters tend to vary. It remains to be determined whether or not juvenile characters can be correlated with adult characters, and if so, whether or not a method can be worked out for recognizing specimens of a given hybrid index in the juvenile stages.

Rosette Dormancy

The major source of rosettes was the thirty-four transplants from twenty-three of the collection sites. These plants were maintained in a well-ventilated greenhouse at Lincoln for a period of four to five months under outside temperatures and light conditions until October. Starting on October 9, 1965, the plants were grown under an eighteen-hour day using two 1,000 watt bulbs placed three feet above the plants. Periodic observations were made to check for signs of bolting until June 1966.

A second source of rosettes was the seedlings from the seed germination study. The seedlings were planted in two-inch pots and maintained under short-day conditions in the greenhouse until they had five leaves in the rosette and had been transplanted into six-inch pots. These were then placed under the same long-day conditions as the others, and were periodically checked for signs of bolting.

The first of the collected rosettes bolted after six weeks of long-day treatment. Two weeks later the second of these plants bolted. At that time it was thought that the long-day treatment was the factor inducing bolting. But in a period of more than six months, only ten of the thirty-four collected plants and four of the twenty-one

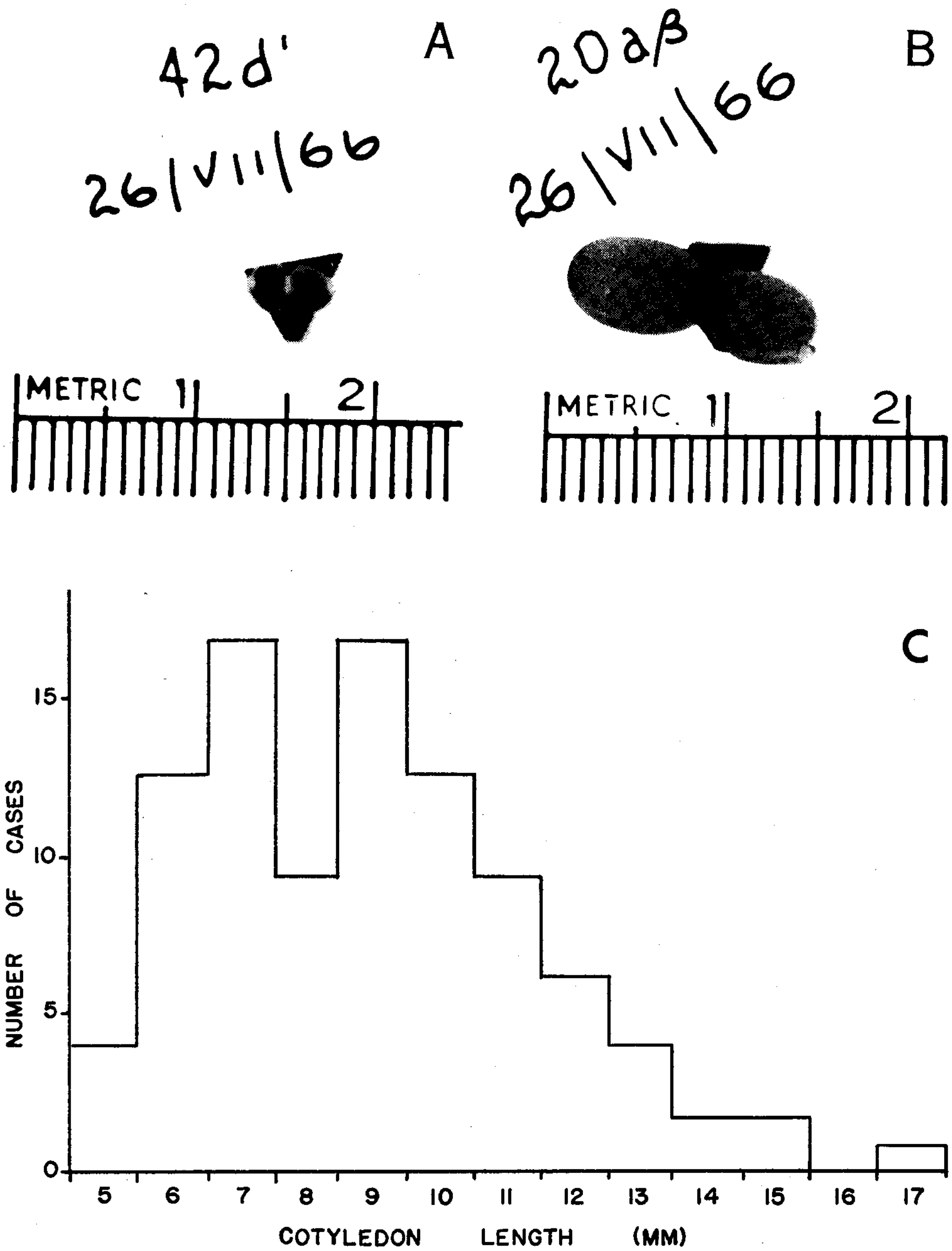


PLATE 11. Cotyledon length. A, seedling from 42d, age two weeks; B, seedling from 20a, age two weeks; C, frequency distribution of cotyledon lengths, age two weeks.

started from seed had bolted. Therefore, the long-day conditions did not appear to produce a consistent bolting response.

The actual size of the rosette was also investigated as a possible factor influencing bolting. Some of those plants which were started from seed bolted although they were much smaller than many of the larger collected specimens which did not bolt. Field observations also showed that some plants with rosette diameters greater than eighteen inches had not bolted, while other plants with diameters of less than twelve inches had bolted. Thus, there appeared to be no correlation between the amount of plant material and the time of bolting.

The factor or factors influencing the time of bolting varied from plant to plant in much the same manner as did the morphological characters, which suggests the possibility of genetic control. Further studies, such as vernalization, might have yielded more data, but these were not attempted in this investigation because of lack of facilities.

Cytological Analysis

It was felt that if the variation found in the *Carduus* populations in Nebraska was the result of hybridization, then variation in chromosome numbers or some chromosomal aberrations might possibly be found. Therefore, immature heads were collected from thirty-six specimens which were pressed from twenty different sites. These heads were preserved in Carnoy's solution (3 ethanol : 1 glacial acetic acid : 1 chloroform) and were given the same collection number as the pressed specimen from which they were taken. To insure rapid fixation the head was cut in half and the phyllaries were removed.

Slides were prepared from single anthers using the standard aceto-carmine technique and were scanned for the various meiotic stages of microsporogenesis. Slides showing some of these stages were then made permanent by using Venetian Turpentine for later, more critical observations.

Flower maturation in the heads was centripetal. In only seven cases from five sites was meiosis found. There appeared to be a diurnal rhythm affecting meiosis. It was noted that three of the sites (7, 8 and 42) with material showing meiotic configuration were collected on bright days between 9:00 A.M. and noon. The time was not noted for the other two sites.

Poddubnaja, in Tischler, 1950 (p. 155), and Moore and Mulligan, 1956, reported the chromosome number of *C. acanthoides* to be

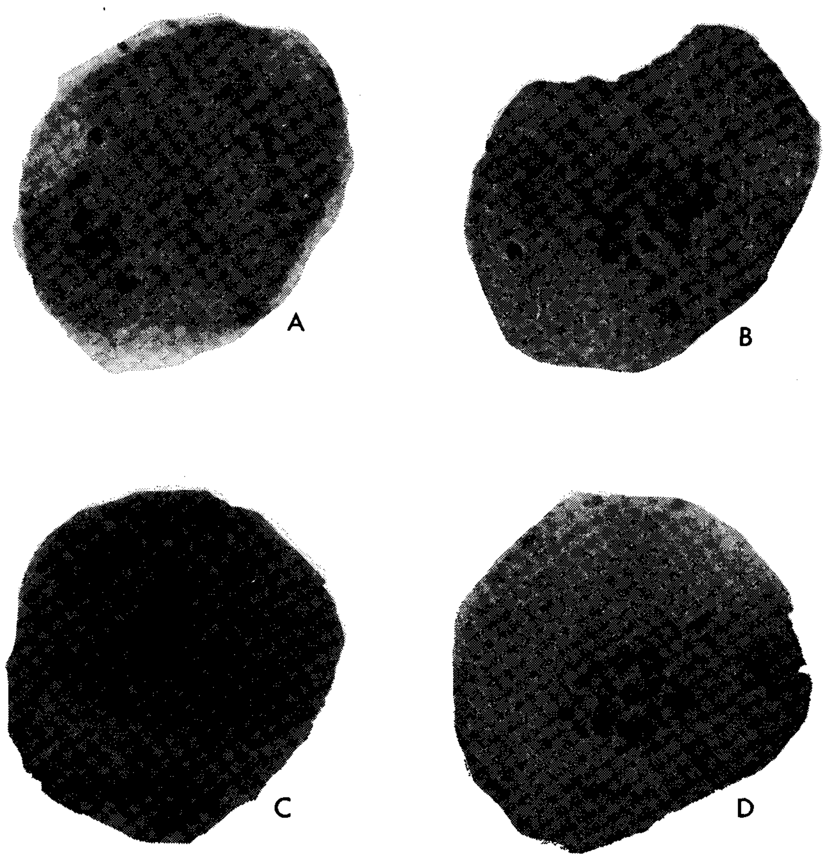


PLATE 12. Meiotic configurations from specimen 42a. A, late anaphase I (8 + 10 + 1 lagging); B, early metaphase I; C, diakinesis; D, late diakinesis.

2n = 22 and *C. nutans* to be 2n = 16. Of the seven specimens in which meiosis was found, six had a chromosome count of 8 + 8 in anaphase I (specimens 7b, 7c, 8a, 8c, 11b and 26b) indicating *C. nutans* numbers. One specimen (42a) had a consistent count of 19 chromosomes suggesting eight *C. nutans* and eleven *C. acanthoides* chromosomes. The separation of these 19 chromosomes was often 8 +11, 9 + 10, and rarely 8 + 10 + 1 lagging chromosome (Plate 12, Figures A and B).

The chromosome numbers of the six specimens were then compared with their hybrid indices. It was found that the six specimens with counts of sixteen chromosomes had intermediate indices ranging from 37 to 56, while specimen 42a with nineteen chromosomes had a relatively low hybrid index of 13.

In the case of specimen 42a, the numerical cytological evidence suggests an F_1 hybrid. If these chromosomes were eight *C. nutans* and eleven *C. acanthoides*, then the plant should have had a hybrid index of approximately 46, the midpoint of the hybrid index range produced by using twenty-three characters. But, the hybrid index indicates that the germ plasm of this specimen was much closer to *C. acanthoides* than to *C. nutans*.

As shown in Figures C and D of Plate 12, chiasmata were present in diakinesis which indicates that crossing-over had occurred. The presence of these chiasmata might be explained in two ways: 1) crossing-over occurring between two homologues; 2) crossing-over occurring between two non-homologous chromosomes. If the former were true, then the crossing-over must occur between either two homologous *C. nutans* chromosomes or two homologous *C. acanthoides* chromosomes. This would mean that one of the chromosomes would have to have been duplicated, and at the same time another chromosome would have to have been lost. Because of the consistent number of chromosomes, a more probable explanation would be that originally crossing-over occurred between at least parts of a *C. nutans* and a *C. acanthoides* chromosome.

With the presence of crossing-over demonstrated in 42a, presumably crossing-over also occurred in the past. Hence, there is no valid reason to assume that eleven of the chromosomes were composed entirely of *C. acanthoides* material and eight chromosomes consisted entirely of *C. nutans* material. On the contrary, from the hybrid index of specimen 42a, only $^{13}/_{92}$ or approximately 15% of its germ plasm was of *C. nutans* origin, instead of the approximately 50% suggested by the chromosome count alone. The evidence seems to indicate that the eight chromosomes appear to possess appreciable amounts of *C. acanthoides* germ plasm and the eleven chromosomes similarly possess considerable *C. nutans* germ plasm. Presumably, this has been caused by previous crossing-over. This would account for the fact that hybrid indices indicated that those plants with sixteen chromosomes carry a higher percentage of *C. acanthoides* germ plasm, more than 50% in some cases, despite the fact that again, the chromosome number alone suggests close relationship to *C. nutans*.

Although it must be admitted that for a cytogenetic study the material is woefully inadequate and that further study would be desirable, the cytological evidence at hand does seem to agree with the morphological evidence in suggesting past hybridization.

Interpretation and Conclusion

Almost all of the plants found in Nebraska, previously identified as *C. nutans* L. or Musk Thistle, appear to be, on the basis of morphological analysis and cytological evidence, the products of interbreeding between *C. nutans* and *C. acanthoides* L. The frequency distribution of hybrid indices indicates that the Nebraska population tends to be closer to the *C. acanthoides* parental type than to the *C. nutans* parental type. This is in agreement with the statement of Moore and Mulligan (1956) that *C. acanthoides* is found in well-drained sandy loam, while *C. nutans* occupies more low-lying grassy pastures that probably have a higher moisture content. The fact that plants in those areas along creek bottoms and drainage ditches with heavier, more moist soil had higher hybrid indices (toward *C. nutans*) than did those sites which were at the top of hills or in drier sandier soil is in line with the above. Also, those sites which covered an area from a hill top to a creek bottom provided a wider range of hybrid indices than did a collection site restricted to a hill top or creek bottom.

Present evidence is that both species were introduced into the eastern part of the state. Although they were not collected until the 1930's, it is quite possible that both species were introduced during the 1920's. In any event, both were introduced before the drought of the 1930's which may have influenced the *Carduus* representatives by selecting drought-resistant plants and by possibly eliminating the parental types. These then crossed producing F_1's which then back-crossed to produce the hybrid swarm present today.

Some of the variation found is shown in Plates 13 to 16. The two extreme types collected are shown in Plates 13 and 16. These two specimens are recognizably distinct. The two specimens in Plates 14 and 15 represent intermediates between the other two. Although at first glance these intermediates appear to be close to the *C. nutans* type (Plate 16), this is merely superficial resemblance. Such obvious characters as the length of the peduncle have been found to be unreliable for diagnostic purposes. Characters such as pappus length together with the size and shape of the phyllaries are much more reliable, although less obvious. Table 8 (p. 29) will permit any interested investigator to assign any given specimen to its approximate position in the hybrid swarm.

As stated in the introduction, this problem was undertaken on the assumption that an increase in the survival ratio resulting in a dramatic increase in the size of the population depends upon the alteration of the environment or of the germ plasm. The results apparently justify the assumption. This is another one of the many instances of plants becoming aggressive in their range extension through hybridization, which is so common among weeds.

PLATE 13. Specimen 30H with a hybrid index of 4 approaching *C. acanthoides* L.

PLATE 14. Specimen 40D with a hybrid index of 41.

PLATE 15. Specimen 29B with a hybrid index of 46.

Plate 16. Specimen 10J with a hybrid index of 78 approaching *C. nutans* L.

Literature Cited

Anderson, Edgar. 1949. Introgressive Hybridization. New York: J. Wiley and Sons, Inc. 109 pp.

Arenes, J. 1949. Contribution a l'etude du Genre Carduus. Memoires du Musee National d'Histoire Naturelle. Nouvelle Serie XXIV, Fascicule *4*:183–255.

Moore, R. J. and G. A. Mulligan. 1956. Natural hybridization between *Carduus acanthoides* and *Carduus nutans* in Ontario. Can. J. Botany *34*:71–85.

Mulligan, G. A. and C. Frankton. 1954. The plumeless thistles (*Carduus spp.*) in Canada. Can. Field-Nat. *68*:31–36.

Poddubnaja, V. 1950. In Tischler, G. Die Chromosomenzahlen der Gefasspflanzen Mitteleurpas. 'S-Gravenhage: Uitgenerij Dr. W Junk. 263 pp.

Snedecor, G. W. 1946. Statistical Methods Applied to Experiments in Agriculture and Biology. Ames, Iowa: The Iowa State College Press. 4th ed. 485 pp.

Appendix

TAL Source Program

```
C       FREQUENCY DISTRIBUTION DR DUDEK 100 VARI-
        ABLES, 200 INTERVALS.
        DIMENSION ITAL(220,100),JX(100),IINT(100),LOX(100),
        NOX(100),SUMX(100),SSQ(100),AVG(100),VAR(100),
        SIGMA(100),SN(100)
        DIMENSION FMT(13)
        COMMON ITAL, SN
      1 FORMAT (11I3)
      2 FORMAT (26I3)
    103 FORMAT (1X,I3,3X,26I4)
    104 FORMAT (1X,/7X,26I4)
    105 FORMAT (1X,/1X,26F5.0)
    106 FORMAT (1X,/(1X,10F13.3))
    107 FORMAT (1X)
   1080FORMAT (10H VARIABLE, I4, 11H HAS SCORE ,I5,
        21H BELOW FIRST INTERVAL)
   1090FORMAT (7H VALUE ,I5,13H OF VARIABLE ,I4,21H
        WOULD BE IN INTERVAL,I5)
    110 FORMAT (/1X,29H    FREQUENCY DISTRIBUTIONS
            ,I2,11H VARIABLES)
    111 FORMAT (1X,/6H TOTAL)
    112 FORMAT (1X,/6H OMITS)
    113 FORMAT (1H1/24H SIZE OF CLASS INTERVAL)
    114 FORMAT (1X,/37H LOWER INTEGRAL LIMIT OF
        LOW INTERVAL)
    115 FORMAT (1X,/6H MEANS)
    116 FORMAT (1X,/(10H VARIANCES))
    117 FORMAT (1X,/20H STANDARD DEVIATIONS)
    118 FORMAT (     1H1      )
    119 FORMAT(80H
      1                          )
    120 FORMAT (13A6)
   1111 FORMAT (1X,22H THE VALUE OF NSET IS ,I3)
   1112 FORMAT (1X,19H THE VALUE OF K IS ,I3)
   1113 FORMAT (1X,34H THE INPUT FORMAT FOR THE
        DATA IS ,13A6)
```

```
1114 FORMAT (1X,19H THE VALUE OF M IS ,I3)
1115 FORMAT (1X,20H THE VALUE OF NO IS ,I3)
1116 FORMAT (1X,24H THE VALUE OF IPTAL IS     ,I3)
3784 FORMAT (1H1)
     WRITE (6,1114) M
     READ (5,2) NSET
     WRITE (6,1111) NSET
   5 WRITE (6,118)
     READ (5,119)
     WRITE (6,119)
     READ (5,2) K,M,NO,IPTAL
     WRITE (6,1112) K
     WRITE (6,1114)M
     WRITE (6,1115) NO
     WRITE (6,1116) IPTAL
     READ (5,2)(IINT(J),J=1,K),(LOX(J),J=1,K)
     DO 8 I=1,M
     DO 8 J=1,K
   8 ITAL(I,J)=0
     DO 12 J=1,K
     N=0
     SUMX(J)=0
     SSQ(J)=0
  12 NOX(J)=0
     READ (5,120) (FMT(J),J=1,13)
     WRITE (6,1113) (FMT(J),J=1,13)
  20 READ (5,FMT)(JX(J),J=1,K),LAST
     IF (LAST.GT.0) GO TO 50
     N=N+1
     DO 40 J=1,K
     IF (NO.GT.0) GO TO 27
     IF (JX(J).EQ.0) GO TO 26
     GO TO 27
  26 NOX(J)=NOX(J)+1
     GO TO 40
  27 X    =JX(J)
     SUMX(J)=SUMX(J)+X
     SSQ(J)=SSQ(J)+ X*X
     IF (LOX(J)-JX(J).LE.0) GO TO 34
     WRITE (6,108)J,JX(J)
     GO TO 40
```

```
34 I=((JX(J)-LOX(J))/IINT(J))+1
   IF (I-M.LE.0) GO TO 39
   WRITE (6,109) JX(J), J, I
   GO TO 40
39 ITAL(I,J)=ITAL(I,J)+1
40 CONTINUE
   GO TO 20
50 DO 54  J=1,K
   SN(J)=N-NOX(J)
   AVG(J)=SUMX(J)/SN(J)
   VAR(J)=(SSQ(J)- SUMX(J)*SUMX(J)/SN(J))/SN(J)
54 SIGMA(J)=SQRT(VAR(J))
   WRITE (6,118)
   WRITE (6,119)
   WRITE (6,110)K
   L1=1
60 L2=L1+25
   IF(L2.GT.K)L2=K
   WRITE (6,107)
   DO 65 I=1,M
   ICHECK=0
   DO 62 J=L1,L2
62 ICHECK=ICHECK+ITAL(I,J)
   IF(ICHECK.EQ.0) GO TO 65
   WRITE (6,103)I,(ITAL(I,J),J=L1,L2)
65 CONTINUE
   L1=L1+26
   IF(K.NE.L2) GO TO 60
80 WRITE (6,111)
   WRITE (6,105) (SN(J),J=1,K)
   WRITE (6,112)
   WRITE (6,104) (NOX(J),J=1,K)
   WRITE (6,113)
   WRITE (6,104) (IINT(J),J=1,K)
   WRITE (6,114)
   WRITE (6,104) (LOX(J),J=1,K)
   WRITE (6,115)
   WRITE (6,106) (AVG(J),J=1,K)
   WRITE (6,116)
   WRITE (6,106) (VAR(J),J=1,K)
   WRITE (6,117)
   WRITE (6,106) (SIGMA(J),J=1,K)
```

```
      IF (IPTAL.EQ.1) CALL PERTAL(M,K)
      NSET = NSET - 1
      IF (NSET.GT.0) GO TO 5
      STOP
      END
$IBFTC PERTAL  NODECK
      SUBROUTINE PERTAL(N,M)
      REAL ISUM
      DIMENSION ITAL(200,100),ISUM(100),PER(100),
      PERT(100)
      COMMON ITAL,ISUM
    1 FORMAT (33H1 PERCENTAGE DISTRIBUTION
      TABLE    /)
    2 FORMAT (5X,I4,3X,17F7.2)
    3 FORMAT (///18H   TOTAL PERCENTAGE    /)
    4 FORMAT (/12X,17F7.2)
  101 FORMAT (1H)
      WRITE (6,1)
      DO 10 K=1,M
   10 PERT(K)=0.0
      L1 = 1
   20 L2=L1+16
      IF (L2 .GT. M) L2 = M
      WRITE (6,101)
      DO 25 J=1,N
      ICHECK=0
      DO 30 K=L1,L2
   30 ICHECK=ICHECK+ITAL(J,K)
      IF(ICHECK.EQ.0) GO TO 25
      DO 35 K=L1,L2
      PER(K)=ITAL(J,K)
      PER(K)=PER(K)*100.0/ISUM(K)
   35 PERT(K)=PERT(K)+PER(K)
      WRITE(6,2)J,(PER(K),K=L1,L2)
   25 CONTINUE
      L1 = L1 + 17
      IF (M .NE. L2) GO TO 20
      WRITE(6,3)
      WRITE(6,4)(PERT(K),K=1,M)
      RETURN
      END
```

CORCO Source Program

```
C       THIS PROGRAM COMPUTES THE SUMS, SUMS
C     OF SQUARES, MEANS, STANDARD DEVIATIONS,
C     AND PEARSON'S CORRELATION COEFFICIENTS OF
C     SETS OF VARIABLES, ALLOWING UP TO 142 VARI-
C     ABLES IN EACH SET. THE FORMULAS USED IN
C     THIS PROGRAM ARE TAKEN FROM ELEMENTARY
C     STATISTICAL FORMULAS BY JOHNSON AND MOR-
C     RIS.
      DIMENSION IXSUM(142),IX2SUM(142),IX(142),
      IR(10153)
      DIMENSION XAVE(142),XSIG(142),XSUM(142),R(142),
      IND(5)
      DIMENSION FMT(13)
      EQUIVALENCE (XAVE(1),XSIG(1),XSUM(1))
    1 FORMAT(I3)
    2 FORMAT(13A4)
    3 FORMAT(3A3,3I3,14X,2I1,1X,2I1)
    4 FORMAT(1H1,10X,33HINTERPRETATION OF
      PARAMETER CARDS)
    5 FORMAT(1H0,2X,41HNUMBER OF THE PROBLEM
      BEING PROCESSED IS  ,I3)
    6 FORMAT(1H0,2X,39HFORMAT SPECIFICATION FOR
      INPUT DATA IS  ,13A4)
    7 FORMAT(1H0,2X,20HTITLE OF PROBLEM IS ,3A3)
    8 FORMAT(1H0,2X,27HNUMBER OF VARIABLES (N)
      IS  ,I3)
    9 FORMAT(1H0,2X,30HNUMBER OF OBSERVATIONS
      (M) IS  ,I3)
   10 FORMAT(1H0,2X,27HNUMBER OF FACTORS (NFE)
      IS  ,I3)
   11 FORMAT(1H0,2X,33HLINEPRINTER OUTPUT ONLY
      REQUESTED)
   12 FORMAT(1H0,2X,33HLINEPRINTER,TAPE  OUTPUT
      REQUESTED)
   13 FORMAT(1H0,2X,38HLINEPRINTER,TAPE, CARD
      OUTPUT REQUESTED)
   14 FORMAT (1H1,27X,3A3//27X,5HSUMS    /)
   15 FORMAT(2X,8(F12.2,3X))
   16 FORMAT (1H0,27X,15HSUMS OF SQUARES /)
   17 FORMAT(1H0,27X,6HMEANS /)
   18 FORMAT (5E14.8)
```

```
19 FORMAT(6H MEANS)
20 FORMAT(1H0,27X,6HST DEV/)
21 FORMAT(20H STANDARD DEVIATIONS)
22 FORMAT (1H1,18X,24HCORRELATION COEFFI-
   CIENTS ,10X,3A3)
23 FORMAT (1X/(1X,20F6.3))
24 FORMAT(16I5)
25 FORMAT(25H CORRELATION COEFFICIENTS)
26 FORMAT(1H0,2X,54HINCORRECT VALUE GIVEN
   FOR IPAR1, PROBLEM NOT PROCESSED)
27 FORMAT(1H0,2X,54HINCORRECT VALUE GIVEN
   FOR IPAR2, PROBLEM NOT PROCESSED)
28 FORMAT(1X/(1X,16F8.3))
29 FORMAT(1X/(1X,18F7.3))
30 FORMAT(1H0,2X,43HVARIABLES READ IN FROM
   FIRST DATA CARD ARE /(1X,16I8))
31 FORMAT(1H0,2X,42HVARIABLES READ IN FROM
   LAST DATA CARD ARE /(1X,16I8))
32 FORMAT(8H(5E14.8))
33 FORMAT(6H(16I5))
34 FORMAT(1H0,2X,49HCARDS PUNCHED FOR
   FACTOR ANALYSIS(CENTROID) WITH ,I3,10H
   VARIABLES)
35 FORMAT(1H0,2X,50HCARDS PUNCHED FOR
   REGRESSION ANALYSIS(MLREG) WITH ,I3,22H
   INDEPENDENT VARIABLES)
36 FORMAT(1H0,2X,66HCARDS PUNCHED FOR
   REGRESSION PARTIAL CORRELATION ANALYSIS
   (PARCOR) )
37 FORMAT(1H0,2X,33HLINEPRINTER,CARD OUT-
   PUT REQUESTED)
38 FORMAT(1H0,2X,10HIODEV1 IS ,I1,5X,10HIODEV2 IS
    ,I1,5X,9HIPAR1 IS ,I1,5X,9H IPAR2IS ,I1)
39 FORMAT (2X,8(E12.6,3X))
   READ(5,1)NP
   NPBP=1
   DO 52 LLL=1,5
52 IND(LLL)=0
50 READ (5,2)(FMT(J),J=1,13)
   READ (5,3) NA,NB,NC,N,M,NFE,IODEV1,IODEV2,
   IPAR1,IPAR2
   IF(IODEV1.LT.5)GO TO 250
```

```
   53 WRITE(6,5)NPBP
      WRITE(6,6)(FMT(J),J=1,13)
      WRITE(6,7)NA,NB,NC
      WRITE(6,8)N
      WRITE(6,9)M
      WRITE(6,10)NFE
      WRITE(6,38)IODEV1,IODEV2,IPAR1,IPAR2
      IF(IODEV1.LT.5)GO TO 262
      IF(IODEV2.EQ.7)GO TO 263
      WRITE(6,11)
   51 IF(IPAR1.GT.1)GO TO 210
      IF(IPAR2.GT.3)GO TO 230
      XM=M
      XXM=M-1
      DO 60 J=1,N
      R(J)=0.
      IXSUM(J)=0
   60 IX2SUM(J)=0
      L=(N*(N+1))/2
      DO 70 I=1,L
   70 IR(I)=0
      DO 100 K=1,M
      READ (5,FMT)(IX(J),J=1,N)
      IF(K.EQ.1)WRITE(6,30)(IX(J),J=1,N)
      IF(K.EQ.M)WRITE(6,31)(IX(J),J=1,N)
      DO 100 J=1,N
      IXP=IX(J)
C
C     COMPUTE SUM
C
      IXSUM(J)=IXSUM(J)+IXP
C
C     COMPUTE SUM OF SQUARES
C
      IX2SUM(J)=IX2SUM(J)+IXP*IXP
      IF(IPAR1.EQ.0)GO TO 100
      IF(J.GE.N) GO TO 100
   80 KK=J+1
      DO 90 L=KK,N
      II=((L-1)*L)/2+J
   90 IR(II)=IR(II)+IXP*IX(L)
```

```
  100 CONTINUE
      DO 110 J=1,N
  110 XSUM(J)=IXSUM(J)
      WRITE(6,14) NA,NB,NC
      WRITE(6,15)(XSUM(J),J=1,N)
      JFOR=0
  111 DO 112 J=1,N
      IF (IX2SUM(J).GE.10000000) JFOR=1
  112 XSUM(J)=IX2SUM(J)
      WRITE(6,16)
      IF(JFOR) 114,115,114
  114 WRITE(6,39)(XSUM(J),J=1,N)
      GO TO 116
  115 WRITE(6,15)(XSUM(J),J=1,N)
  116 DO 113 J=1,N
  113 XSUM(J)=IXSUM(J)
      DO 120 J=1,N
C
C     COMPUTE MEANS
C
  120 XAVE(J)=XSUM(J)/XM
      WRITE(6,17)
      WRITE(6,15)(XAVE(J),J=1,N)
      IF(IPAR2.NE.2)GO TO 130
      IF(IODEV1.GT.4)GO TO 121
      L = IODEV1
      WRITE(L,18)(XAVE(J),J=1,N)
  121 IF(IODEV2.NE.7)GO TO 130
      L = IODEV2
      WRITE(L,32)
      WRITE(L,18)(XAVE(J),J=1,N)
  130 DO 140 J=1,N
      X=IX2SUM(J)
C
C     COMPUTE STANDARD DEVIATIONS
C
  140 XSIG(J)=SQRT((X-XAVE(J)*XAVE(J)*XM)/XXM)
      WRITE(6,20)
      WRITE(6,15)(XSIG(J),J=1,N)
      IF(IPAR2.NE.2)GO TO 150
```

```
      IF(IODEV1.GT.4)GO TO 141
      L=IODEV1
      WRITE(L,18) (XSIG(J),J=1,N)
  141 IF(IODEV2.NE.7)GO TO 150
      L=IODEV2
      WRITE(L,18)(XSIG(J),J=1,N)
  150 IF(IPAR1.EQ.0)GO TO 270
      WRITE(6,22) NA,NB,NC
C
C     COMPUTE CORRELATION COEFFICIENTS
C
      KK=1
      DO 200 K=1,N
      R(K)=1.
      L=(K*(K+1))/2
      LL=L-1
      IF(K.LE.1)GO TO 165
      J=1
      DO 160 II=KK,LL
      X=IXSUM(K)
      Y=IXSUM(J)
      X=X*Y
      Y=IR(II)
      XTEST=XM*XXM*XSIG(K)*XSIG(J)
      IF(XTEST.EQ.0) GO TO  159
      R(J)=(XM*Y-X)/XTEST
      GO TO 160
  159 R(J)=1.
      YTEST=XM*Y-X
      IF(YTEST.EQ.0) R(J)=0.
  160 J=J+1
  165 IF(N.LT.16)WRITE(6,28)(R(J),J=1,K)
      IF(N.LT.16)GO TO 180
      IF(N.LT.18)WRITE(6,29)(R(J),J=1,K)
      IF(N.LT.18)GO TO 180
  170 WRITE(6,23)(R(J),J=1,K)
  180 J=0
      DO 190 II=KK,L
      J=J+1
  190 IR(II)=1000.*R(J)
```

```
200 KK=L+1
    IF(IPAR2.EQ.0)GO TO 270
    IF(IODEV1.GT.4)GO TO 201
    K=IODEV1
    WRITE(K,24)(IR(J),J=1,L)
201 IF(IODEV2.NE.7)GO TO 270
    K=IODEV2
    IF(IPAR2.EQ.3)GO TO 202
    WRITE(K,33)
202 WRITE(K,24)(IR(J),J=1,L)
    GO TO 270
210 WRITE(6,26)
    DO 220 K=1,M
    READ(5,FMT)(IX(J),J=1,N)
220 CONTINUE
    GO TO 270
230 WRITE(6,27)
    DO 240 K=1,M
    READ(5,FMT)(IX(J),J=1,N)
240 CONTINUE
    GO TO 270
250 LLL=IODEV1+1
    IF(NPBP.EQ.1)GO TO 255
    IF(IND(LLL).EQ.0)GO TO 255
    GO TO 53
255 REWIND IODEV1
    IND(LLL)=1
    GO TO 53
260 WRITE(6,13)
261 IF(IPAR2.EQ.1)WRITE(6,34)N
    IF(IPAR2.EQ.2)WRITE(6,35)N
    IF(IPAR2.EQ.3)WRITE(6,36)
    GO TO 51
262 IF(IODEV2.EQ.0)WRITE(6,12)
    IF(IODEV2.EQ.7)GO TO 260
    GO TO 51
263 WRITE(6,37)
    GO TO 261
270 NPBP=NPBP+1
    IF(NPBP.LE.NP)GO TO 50
```

```
      DO 280 LLL=1,5
      IODEV1=LLL-1
      IF(IND(LLL).EQ.1)REWIND IODEV1
  280 CONTINUE
      STOP
      END
```

HYBIX Source Program

```
      INTEGER UPDOWN,FMT
      DIMENSION FMT(40),MIN(40),INT(40),NOINT(40),
      MAX(40),IDATA(40)
      DIMENSION MDATA(40),UPDOWN(40)
    1 FORMAT(2I3,I1)
    2 FORMAT(20I4)
    3 FORMAT(20A4/20A4)
    4 FORMAT(40H NEGATIVE OUTPUT  ERROR IN
      CLASS MAXIMUM)
    5 FORMAT(1X,16HNO OF VARIABLES ,I3,13H NO OF
      CARDS=,I3, 5H SEQ ,I1)
    6 FORMAT(1X,15H MINIMUM VALUE ,(19(1X,I5)/
      21(1X,I5)))
    7 FORMAT(1X,20A4/1X,20A4)
    8 FORMAT(1X,15H NO OF INTERVALS,(19(1X,I5)/
      21(1X,I5)))
    9 FORMAT(1X,15HINTERVAL VALUE,(19(1X,I5)/
      21(1X,I5)))
   10 FORMAT(1X,15H MAXIMUM VALUE,(20(1X,I4)/
      20(1X,I4)))
   11 FORMAT(19H DIMENSION OVERFLOW)
   12 FORMAT(1X,6HUPDOWN,(20(1X,I4)/20(1X,I4)))
   13 FORMAT(1X,A4,(1X,20I6))
C     NOV  IS THE NUMBER OF VARIABLES
C     NOC  IS THE NO OF CARDS
C     UPDOWN  IS THE CONTROL FOR ASCENDING
      OR DESCENDING. 0 UP 1 DOWN
      READ(5,1) NOV,NOC
      IF(NOV.GT.40) WRITE(6,11)
      WRITE(6,5)NOV,NOC
      READ(5,2) (MIN(I),I=1,NOV)
      WRITE(6,6)(MIN(I),I=1,NOV)
      READ(5,2) (INT(I),I=1,NOV)
```

```
      WRITE(6,9)(INT(I),I=1,NOV)
      READ(5,2) (NOINT(I),I=1,NOV)
      WRITE(6,8)(NOINT(I),I=1,NOV)
      READ(5,2)(UPDOWN(I),I=1,NOV)
      WRITE(6,12)(UPDOWN(I),I=1,NOV)
      DO 20 I=1,NOV
   20 MAX(I)=MIN(I)+(NOINT(I)*INT(I))
      WRITE(6,10) (MAX(I),I=1,NOV)
      READ(5,3) (FMT(I),I=1,40)
      WRITE(6,7)(FMT(I),I=1,40)
      DO 100 M=1,NOC
      READ(5,FMT)IDENT,(IDATA(I),I=1,NOV)
      MSUM=0
      DO 50 I=1,NOV
      DATA=IDATA(I)
      DMIN=MIN(I)
      DINT=INT(I)
      DMAX=MAX(I)
      IF(UPDOWN(I).GT.0) DATA=DMAX-DATA
      IF(UPDOWN(I).LE.0) DATA=DATA-DMIN
      DATA=DATA/DINT
      MDATA(I)=DATA
      MSUM=MSUM+MDATA(I)
      IF(MDATA(I).LT.0) WRITE(6,4)
   50 CONTINUE
      WRITE(6,13)IDENT,(MDATA(I),I=1,NOV),MSUM
  100 CONTINUE
      STOP
      END
```