Technical News Feature

Agronomic Potential and Seed Composition of Cuphea, an Annual Crop for Lauric and Capric Seed Oils

FRANK HIRSINGER, Dept. of Crop Science, Oregon State University, Corvallis, OR[1]

ABSTRACT

Cuphea is an herbaceous summer annual plant native to Mexico. The seed oil contains various medium-chain fatty acids which, depending on the species, account for 40 to more than 80% of the total fatty acids. Cuphea oil could be a substitute for coconut- and palm kernel oil because of the high lauric acid content, but also could serve as a natural source of capric acid, which presently comes mainly from petrochemicals.

Agronomic research recently begun at Oregon State University is directed toward adaptation and yield improvement of Cuphea. Initial Oregon field experiments in 1983 indicated that Cuphea is well adapted to the Willamette Valley. The plant, however, is not yet adapted to current farm production technology. Slow emergence and seedling growth may be altered by breeding and selection. Seed indehiscence and indeterminate growth already have been altered through mutations.

In recent experiments seed yield could be increased significantly by multiple harvests, which indicates that further gain could be expected through improved technology. Present yield potential of Cuphea is about 300 kg of oil per hectare.

INTRODUCTION

Today there is an increasing need for medium chain triglycerides (MCT) to be used for industrial purposes (1,2). Since the late 1960's, Cuphea species have been known as a potential source of MCT, as substitutes for palm kernel and coconut oil. They are native to Mexico and never have been domesticated. Agronomic studies indicated that some Cuphea species of the Mexican section Heterodon have sufficient growth potential (3,4,5,6). Mutation experiments with *C. aperta, C. lanceolata, C. procumbens, C. paucipetala, C. tolucana* and *C. wrightii* have shown that certain wild plant characteristics, like seed indehiscence, sticky hairs and indeterminate plant growth, can be overcome (6,7). There is, however, a lack of information about seed yield of Cuphea species. This study reports yield data from field experiments with 30 different Cuphea species and varieties.

MATERIALS AND METHODS

The Cuphea accessions were grown near Davis, California, in 1982. Seed was provided by Graham et al. (8,9) and by Hirsinger and Knowles (5). Seeds were pregerminated, planted in a greenhouse and transplanted to the field in late April, with 8-50 surviving plants per plot (Fig. 1). The day of flowering was defined as the day when the first 3 flowers appeared on one plant. When plants started to set seeds, one representative single plant was harvested about every 10 days until late August in 10 harvests.

Cuphea species generally shatter their seeds easily and have indeterminate plant growth with continuous flower and seed production over a period of one to two months. The described method of multiple harvesting seemed to be an appropriate way of measuring the yield potential, because it allowed maximum seed recovery. The harvested seeds were cleaned, dried and weighed. The "days till seed yield" were defined as the days from planting until 0.6 g of seeds per plant were accumulated. Plant height was measured at the last harvest. The weight of 1000 seeds was calculated, and seed fatty acids were analyzed by gas liquid chromatography according to Thies (10).

FIG. 1. Planting of different Cuphea species (foreground and background right) and seeding experiments with *C. lanceolata, C. wrightii, C paucipetala,* and *C. tolucana* at Davis (July, 1982).

According to a simple selection index, the measurements (with the exception of fatty acids) were transformed into 5 quality groups, with group 1 always representing the best or most desirable group of plants. In column 7 of Table I these grouped data are summarized as "Σ groups." The rank of the species, given in Column 8, is an indicator of the agronomic value of a species. For the different traits the groups were defined as shown in Table II.

RESULTS AND DISCUSSION

Plant height (Table I) ranged from 31 cm (*C. carthagenensis* and *C. glutinosa*) to 106 cm (*C. angustifolia*) with a mean of 59 cm. The minimal height for acceptable agronomic production is approximately 45 cm. In smaller plants, stand formation as well as mechanical harvesting are adversely affected. *C. leptopoda* seems to be the only tall species that also reaches good values in other traits. There is a significant correlation between plant height and seed weight (Table III). This correlation, however, has only limited value for future selection work because it is not significant in Heterodon species which are the only ones presently adapted to agronomic production (3,5).

Seed weight ranged from 0.18 g (*C. racemosa*) to 4.21 g/1000 seeds (*C. lophostoma*) with an overall mean of 1.94 g for all species. The Heterodon species, however, averaged 2.5 g, which is three times the seed weight of the

[1]New address: Henkel KGaA, Postfach 1100, D-4000 Düsseldorf, West Germany.

TABLE I

Agronomic and Chemical Data as Well as Grouped Data and Summarized Grouped Data, and Ranks for 30 Cuphea Species

Section and species[1]	Days till flower		Days till yield		Seed yield /plant		Plant height		1000 Seed weight		Fatty acid	Σ Grp.	Rank 2)
		*		*	g	*	cm	*	g	*	No. C	*	
SECT. CUPHEA													
C. racemosa	75	4	-	5	0	5	32	5	.18	5	18	24	28a
SECT. BRACHYANDRA													
C. carthagenensis	65	3	100	3	6.7	3	31	5	.69	5	12	19	19a
C. aperta	70	3	115	4	1.6	4	37	4	.47	5	12	20	21a
SECT. EUANDRA													
C. glutinosa	68	3	115	4	1.4	4	31	5	.98	5	12	21	23a
SECT. HETERODON													
C. glossostoma	47	1	100	3	9.2	2	63	3	1.95	4	12	13	7a
C. laminuligera	38	1	85	1	10.1	1	64	3	2.13	3	12	9	2a
C. lophophora	72	3	115	4	4.6	3	45	4	1.91	4	12	18	16a
C. lutea	31	1	93	2	9.1	2	54	3	2.49	3	12	11	5a
C. tolucana	53	2	100	3	2.3	4	54	3	1.36	5	12	17	13a
C. wrightii	64	2	93	2	6.0	3	45	4	1.61	4	12	15	9a
C. koehneana	80	4	110	4	1.5	4	91	1	2.95	3	10	16	11a
C. angustifolia	95	5	-	5	0	5	106	1	.83	5	10	21	24b
C. paucipetala	62	2	93	2	1.1	4	73	2	2.24	3	10	13	8b
C. pauc. (K-mut.)	66	3	100	3	0.7	4	51	3	2.13	3	10	16	12b
C. pauc. (new var.)	64	2	100	3	1.6	4	50	3	1.22	5	10	17	14b
C. leptopoda	70	3	93	2	15.0	1	82	1	3.67	1	10	8	1
C. inflata	65	3	85	1	8.7	2	77	2	3.85	1	10	9	3b
C. viscosissima	65	3	85	1	9.3	2	63	3	2.99	2	10	11	6b
C. lanceolata	84	4	130	5	0.8	5	80	1	3.13	2	10	17	15c
C. procumbens (2n)	75	4	110	4	2.5	4	68	2	3.43	1	10	15	10b
C. procumbens (4n)	80	4	-	5	0.6	4	43	4	2.65	2	10	19	20b
C. lophostoma	60	2	85	1	1.8	4	77	2	4.21	1	10	10	4
C. calcarata	92	5	115	4	0.9	4	63	3	1.83	4	10	20	22b
C. llavea (2n)	78	4	-	5	0.3	5	64	3	3.32	1	10	18	17b
SECT. MELVILLA													
C. ignea	80	4	-	5	0	5	32	5	1.24	5	10	24	29b
SECT. LEPTOCALYX													
C. palustris	73	3	93	2	0.8	5	53	3	1.48	5	14	18	18c
C. aequipetala	93	5	-	5	0.1	5	69	2	1.06	5	14	22	25a
SECT. DIPLOPTYCHIA													
C. cyanea	78	4	-	5	0	5	31	5	.66	5	8	24	30c
C. hookeriana	95	5	-	5	0	5	65	2	.95	5	8	22	26b
C. painteri	98	5	-	5	0	5	65	2	.56	5	8	22	27c
Mean	71	3	101	3	3.2	4	59	3	1.94	3	10	17	-

* Grouped data range from 1 (best) to 5 (worst).
[1]Arranged according to Koehne (11).
[2]Ranks range from 1 to 30. Letters indicate there is more than one species in that rank, e.g. 12b is the second species with a group sum of 16.

TABLE II

Definition of Groups for Rating of Agronomic Traits

Group / Trait	1 excellent	2 very good	3 good	4 fair	5 poor
Days till flower	≤50	50-64	65-74	75-85	≥85
Days till seed yield	≤86	86-93	94-101	102-115	≥115
Seed yield (g)	≥10	7-10	4-6.9	0.6-3.9	< 0.6
Plant height (cm)	≥79	65-79	50-64	35-49	≤35
Seed weight (g/1000)	> 3.3	2.6-3.3	2.1-2.5	1.6-2	< 1.6

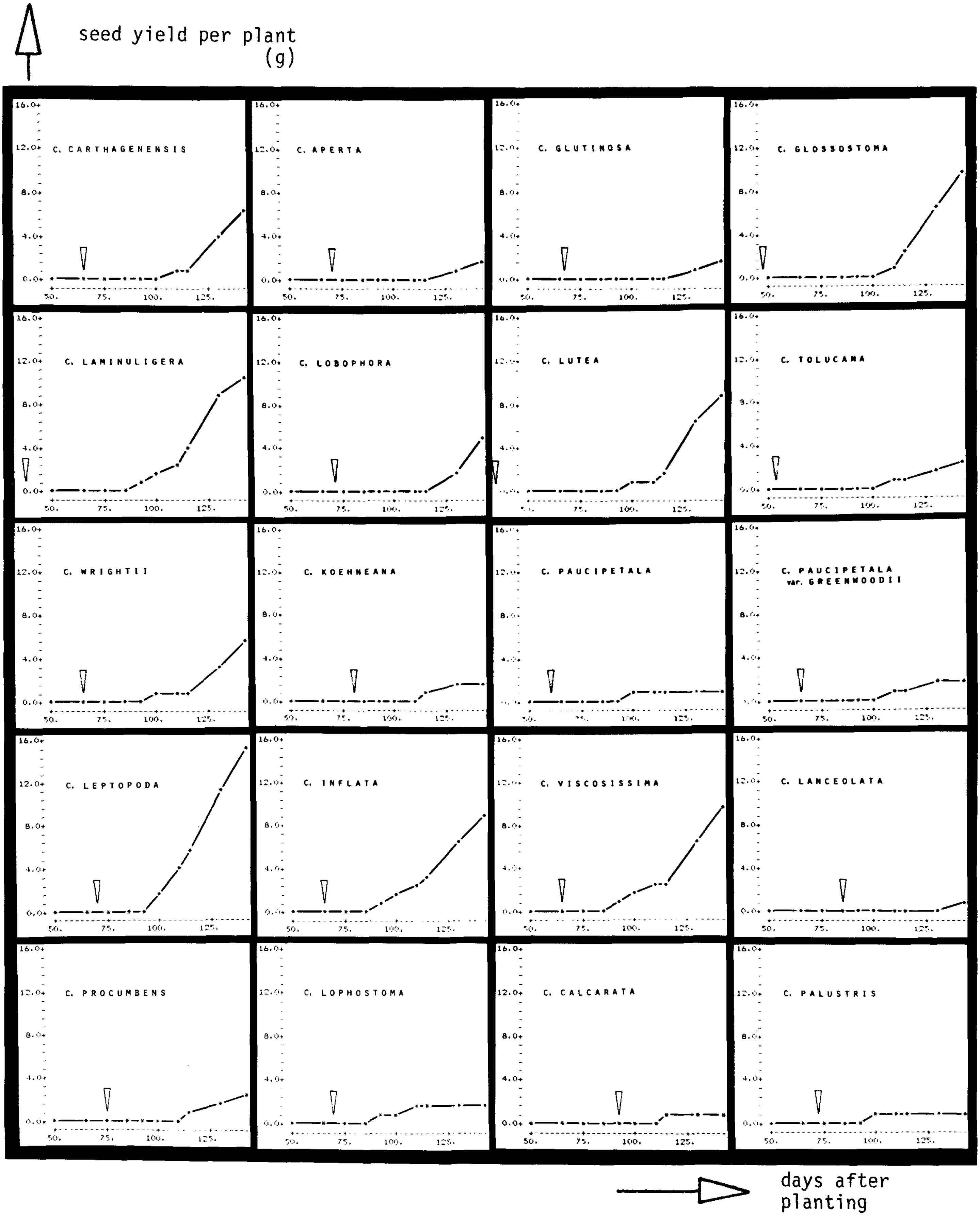

FIG. 2. Seed yield development of 20 Cuphea species after 10 harvests. ∇-arrows indicate start of flowering.

TABLE III

Linear Correlation Coefficients Between Various Agronomic and Chemical Traits of 30 Cuphea Species. (In parentheses correlation coefficients from 20 Cuphea species of section Heterodon)

	Days till seed yield[1]	Seed yield	Plant height	1000 Seed weight	Chain length of fatty acid
		g/plant	cm	g	C-atoms
Days till flower	0.60** (0.64**)	-0.62** (-0.56*)	0.19 (0.38)	-0.26 (0.01)	-0.27 (-0.67**)
Days till seed yield[1]		-0.58** (-0.59*)	-0.15 (0.05)	-0.29 (-0.18)	-0.04 (-0.11)
Seed yield (g/plant)			0.13 (-0.03)	0.41 (0.24)	0.06 (0.39)
Plant height (cm)				0.52** (0.25)	-0.33 (-0.47*)
1000 seed weight (g)					-0.30 (-0.42)

[1]Calculated only for those 21 (17 Heterodon) species that yielded more than 0.6 g of seeds per plant.
*,**Significantly different from zero at the 0.05 and 0.01 probability level.

remainder of the Cuphea species in the test (0.83). Only *C. angustifolia* seed with 0.83 g/1000 seeds is similar to that of the other sections.

A seed weight of 2.5 g is acceptable for economic production. Smaller seeds impede planting, seed vigor, stand establishment, harvesting and cleaning.

Different fatty acid patterns in Cuphea have been of major interest since the genus was "rediscovered" by American chemists in the early 1960's (12,13). Graham et al. (8,9) described the fatty acid composition of seeds of 46 Cuphea species and established a new chemotaxonomic classification of the genus and the relationship among sections.

In this study, 5 different fatty acid patterns were found (Table I). Some species synthesize very high amounts of capric acid (e.g. *C. leptopoda*, 87% C 10:0), while others have high amounts of lauric acid (e.g. *C. aperta*, 72% C 12:0), caprylic acid (e.g. *C. cyanea*, 68% C 8:0) or myristic acid (e.g. *C. palustris*, 64% C 14:0). A small group of species that indicate a beginning diversification within the genus produce an almost "normal" fatty acid pattern with medium amounts of linoleic acid (e.g. *C. racemosa*, 59% C 18:2). Cuphea seed oils with high amounts of lauric acid (12 C atoms) represent an optimum for industrial applications, because lauric acid offers the best physical and chemical characteristics for the manufacture of solvents and detergents. The seed oils of those species could be substituted for coconut- and palm kernel oil. Capric acid, especially when it is as highly concentrated as in two-thirds of the Heterodon species, also offers a highly desirable product which presently is obtained only from petrochemicals.

In Heterodon species there are two significant negative correlations between fatty acid chain length and plant height as well as days till flower. The taller the plant, the shorter the fatty acid chain of the seeds (r = −0.47*, Table III) and the earlier the flowering starts, the longer is the fatty acid (r = −0.67**). Earlier experiments under optimum greenhouse conditions (Hirsinger, unpublished data) indicated that *C. wrightii* sets seed as early as 30 days after seeding. Under the same conditions, *C. procumbens*, a capric acid species, did not initiate seed set until 60 days after seeding. *C. procumbens*, however, is described to have a fatty acid synthesizing rate that is more than 10 times higher than that of a "normal" oil crop like rapeseed (14). That efficiency obviously must be higher in *C. wrightii* considering the overall energy situation of the plant.

The time from planting to flowering ranged from 31 days (*C. lutea*) to 98 days (*C. painteri*), with a mean of 71 days for all 30 Cuphea species in the test (Table I). The time from seeding to seed yield ranged from 85 days (*C. laminuligera*) to 130 days (*C. lanceolata*), with a mean of 101 days. Some species never produced as much as 0.6 g of seed per plant, probably due to the arid summers in the

FIG. 3. A yield evaluation experiment with *Cuphea wrightii* at seed maturity. Sown April 16 in 40-in. beds, 2 rows per bed. Davis (Sept. 3, 1983).

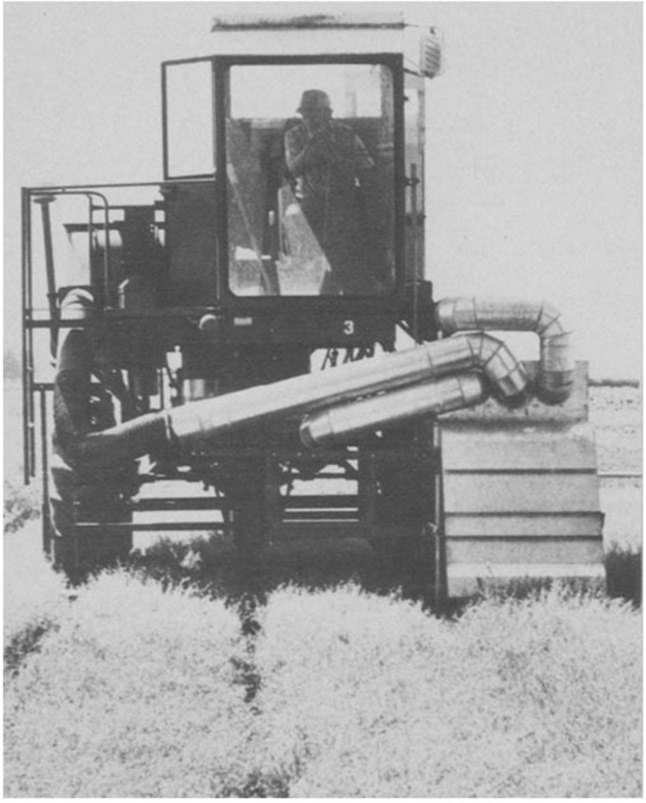

FIG. 4. Vacuum harvesting of *Cuphea wrightii* with a modified cotton picker. The 2 center rows have just been harvested. A second harvest was done 2 weeks later. Davis (Sept. 8, 1983, same experiment as in Figure 3).

Sacramento Valley. For example, *C. racemosa* is known to be well adapted to the high humidity in subtropical areas of Brazil. In our field experiment this species started to flower relatively early (75 days after planting) but never produced substantial amounts of seeds, probably because of poor seed development and premature abortion, which was never observed under humid greenhouse conditions.

Other species, such as *C. laminuligera, C. lutea, C. wrightii, C. leptopoda,* and *C. viscosissima,* seemed to be better adapted to the local climatic conditions of our experiment because of early flowering and seed set. The seed yield of these species ranged from 6 to 15 g per plant, substantially higher than the mean of 3.2 g for all species. The linear correlation coefficients (Table II) between days till flowering and days till seed yield, as well as seed yield, which were highly significant in all 3 combinations, indicate a strong correlation among those 3 traits. In future selection work, therefore, early flowering and seed set in Cuphea may be a strong indicator of high seed yield. This conclusion is based on the efficient way in which Cuphea species accumulate seed weight by continuous flowering and seed set over a period of up to two months. The "indeterminate plant growth," a typical wild plant characteristic, cannot be considered to be a positive trait per se. In combination with "seed indehiscence," another wild plant trait, it facilitates increased seed yield through multiple harvesting, as was practiced in this experiment.

Figure 2 illustrates the time-dependent increase of harvested seed yield for those Cuphea species that reached a total yield of more than 0.7 g/plant. It is evident that the entire seed yield could not be achieved with only one harvest. In *C. leptopoda,* for example, multiple harvests probably are required about 110, 125 and 140 days after planting, or approximately every 2 weeks after seed formation. Large field experiments near Davis, CA, and Corvallis, OR in 1983 with mechanical and vacuum equipped harvesters indicated that nondestructive multiple harvests are feasible (Figs. 3 and 4). The seed yield of those experiments was up to 900 kg/ha and, assuming 34% oil, an oil yield of over 300 kg per ha could be obtained. Since these experiments did not have optimum weed control, planting rate, irrigation and other production factors, and considering that relatively wild germplasm was used, this yield indicates a good starting point for an agronomic research program.

The amount and type of research that still needs to be conducted is apparent from the gap between the single plant yield of 6 g and the plot yield of 900 kg/ha. Such plot yields equal 90 g of seeds per m^2, which would amount to 15 plants/m^2 with 6 g of seeds each. According to today's knowledge, at least 40 to 60 plants per m^2 is more realistic for stand formation in *C. wrightii.* This would increase the potential seed yield of *C. wrightii* to 2400 or even 3600 kg/ha. Similar calculations for *C. laminuligera* indicate a potential seed yield of 4040 to 6060 kg/ha and for *C. leptopoda* 6000 to 9000 kg/ha.

ACKNOWLEDGMENTS

This research was supported by the Henkel KGaA, Düsseldorf, Federal Republic of Germany, the Deutsche Forschungsgemeinschaft, Bonn, Federal Republic of Germany, and the Procter and Gamble Co., Cincinnati, OH. My wife helped me with all the field work; the Department of Agronomy and Range Science, UC Davis, provided technical support, and Robert A. Kepner and the Department of Agricultural Engineering, at UC Davis changed a cotton picker into an effective Cuphea vacuum harvester.

REFERENCES

1. Stein, W., Fette, Seifen, Anstrich. 84:45 (1982).
2. Stein, W., Improvement of seed oils from an industrial point of view: non-edible use. In: Improvement of oil seeds and industrial crops. International Atomic Energy Agency, Vienna, p. 233 (1982).
3. Hirsinger, F., Angew. Botanik 54:157 (1980).
4. Hirsinger, F., Fette, Seifen, Anstrich. 82:385 (1980).
5. Hirsinger, F., and P.F. Knowles, Econ. Bot. 38:439 (1984).
6. Röbbelen, G., and F. Hirsinger. Cuphea, the first annual oil crop for the production of medium-chain triglycerides (MCT). In: Improvement of oil seeds and industrial crops, IAEA, Vienna, p. 161 (1982).
7. Hirsinger, F., Z. Pflanzenzüchtg. 85:157 (1980).
8. Graham, Shirley A., F. Hirsinger and G. Röbbelen., Amer. J. Bot. 68:908 (1981).
9. Graham, Shirley A., F. Hirsinger and G. Röbbelen. Bio Science 31:244 (1981).
10. Thies, W., Z. Pflanzenzüchtg. 65:181 (1971).
11. Koehne, E., Lythraceae IV, 216, In: Das Pflanzenreich, edited by A. Engler, Regni vegetabilis conspectus, Heft 17 (1903).
12. Wilson, T.L., T.K. Miwa and C.R. Smith, JAOCS 37:675 (1960).
13. Miller, R.W., F.R. Earle, I.A. Wolff and Q. Jones, JAOCS 41:279 (1964).
14. Slabas, A.R., P.A. Roberts, J. Ormesher and E.W. Hammond, Biochim. Biophys. Acta 711:411 (1982).