

AGRICULTURAL MANAGEMENT OF *CUPHEA* AND COMMERCIAL PRODUCTION IN THE UNITED STATES

Russ Gesch^a, Frank Forcella^a, Alan Olness^a, Dave Archer^a and Andrew Hebard^b

^a USDA-ARS, North Central Soil Conservation Research Lab, Morris, MN 56267, USA.

^b Technology Crops International, Winston-Salem, NC 27116, USA.

Abstract

Cuphea (*Cuphea* sp.) is a new oilseed crop that has undergone agricultural domestication for about the past 20 years. Its seed is rich in small- and medium-chain fatty acids that are highly valued for manufacturing soaps, detergents, personal care products, and industrial lubricants. Since 1999, our research group has focused on developing an agricultural management strategy for cuphea production utilizing conventional technologies to minimize the need for specialized equipment. Our long-range goal is to provide an economically viable crop that can be rotated with maize and soybean in a region of the U.S. predominated by these two crops. The semi-domesticated genotype PSR23 that was developed through the interspecific hybridization of *Cuphea viscosissima* Jacq. (native to the U.S.) x *C. lanceolata* W.T. Aiton (native to Mexico) performs well in temperate, short growing-season climates. PSR23 is an annual plant that has a relatively shallow root system, a high water requirement for growth, and prefers mild temperatures, particularly during its reproductive phase. By using the best management practices developed by our team, we have obtained seed yields as high as 1400 kg ha⁻¹.

The summer of 2004 marked the first year for an experimental commercialization of cuphea. Technology Crops International, in cooperation with the USDA Agricultural Research Service, contracted six farmers within a 32 km radius of Morris, Minnesota (45.35°N, 95.53°W) to produce from 2 to 4 ha each of cuphea for a total of 18.6 ha. Some of the crop (about 2.6 ha) was lost to severe weather and

* Corresponding author: Tel.: +1-320-589-3411 x:132; Fax: +1-320-589-3787 – E-mail address: gesch@morris.ars.usda.gov



herbicide drift from other nearby crops, but the harvestable plantings produced seed yields ranging from approximately 78 to 744 kg ha⁻¹ at 12% moisture. Valuable knowledge was learned through this experience that might not have been gained by plot-scale experiments alone. For instance, post-harvest management of seed on a large-scale (e.g., drying, cleaning, and storing) was problematic, indicating a further need for research and development in this area. Overall, the 2004 commercialization project made considerable progress in advancing cuphea towards large-scale production. This paper summarizes some of our research results regarding the best agronomic practices for cuphea production and reports on results obtained from the 2004 commercialization project.

Keywords: Cuphea; New crop; Medium chain fatty acid; Crop production.

1. INTRODUCTION

The genus *Cuphea* (plant family Lythraceae) contains about 265 species native to North, Central, and South America. Many of these species have the ability to synthesize and store medium chain fatty acids (MCFA) in their seeds. Some of these MCFAs such as capric, lauric, and myristic acids are important feedstocks in manufacturing a wide range of chemical products. Recent developments have also proven that MCFAs are a viable replacement for motor oil (Cermak and Isbell, 2004) and diesel fuel (Geller *et al.*, 1999) that originate from petroleum.

Currently, coconut (*Cocos nucifera* L.) and palm (*Elaeis guineensis* Jacq.) are the only plant-derived sources of MCFAs used in chemical manufacturing, and developed countries import about 2.5 million Mt annually. Developing a MCFA-rich oilseed crop for temperate climates would be beneficial to industry and producers located in higher latitudes. Some species of *Cuphea* are known to flourish in temperate climates (Graham, 1989). Hirsinger (1985) was one of the first to show that several *Cuphea* species have agronomic potential. Since then, advances have been made in domesticating *Cuphea* (henceforth referred to as "cuphea") for commercial use. As with most wild plant species, the largest barriers to domesticating cuphea have been seed shattering, seed dormancy, and self-fertility. Recently, these barriers have been partially overcome through the development of genotypes arising from the interspecific hybridization of *Cuphea viscosissima* Jacq. x *C. lanceolata* W.T. Aiton. One selected genotype from this cross is PSR23 (Knapp and Crane, 2000) that produces non-dormant seed and has considerably improved seed retention and self-fertility over its wild relatives.

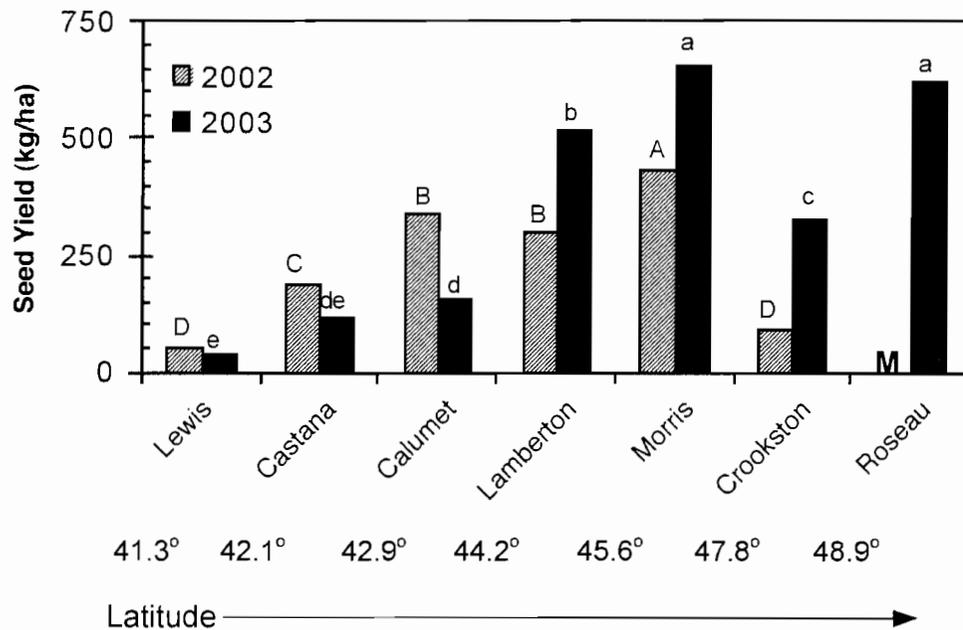
In 1999, our research group began working with just a few grams of PSR23 cuphea seed to determine its agronomic potential for the midwestern U.S. Our primary objectives have been to develop best management practices for cuphea production and determine its response to environmental factors such as temperature, soil moisture, light, and soil type. Since the initiation of our work, substantial progress has been made, and the summer of 2004 marked the first year when on-farm commercial production of cuphea was conducted in the U.S. This was accomplished through close collaborative effort with industry (Technology Crops International, Winston-Salem, NC). Although the production scale in 2004 was small (about 17 ha), the results were encouraging and suggest that large-scale production is feasible in the near future. The focus of this paper is to briefly review some of our key research findings and give an overview of the 2004 commercialization project.

2. CUPHEA AGRONOMIC MANAGEMENT

2.1. Environmental limitations of domesticated cuphea

Cuphea (PSR23) grows well in west central Minnesota (45.6 °N latitude) and when planted in mid May and harvested in mid to late September can produce seed yields as high as 1400 kg ha⁻¹. Yield information for PSR23 in other areas is sparse, although Knapp and Crane (2000) reported 795 kg ha⁻¹ from a site in Corvallis, Oregon (44.3 °N) and seed yields around Peoria, Illinois (40.5 °N) tended to be less than Minnesota (Terry Isbell, personal communication). Forcella *et al.* (2005) grew PSR23 at seven sites along a south-north transect from Iowa to Minnesota (latitude range of 41.3° to 48.9 °N). As shown in Figure 1, seed yield generally increased with latitude in both years of the study. Although many factors may have influenced these yield differences, temperature and available soil moisture variations were the more important. Along this transect, both seasonal temperature and potential evapotranspiration increase with decreasing latitude. We have previously shown that cuphea prefers mild temperatures for growth. PSR23 shows an optimum for photosynthesis and growth at a mean daily temperature of about 24° (Gesch *et al.*, 2002b), which is considerably less than that for agronomic crops such as corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.].

Figure 1. Seed yields of PSR23 cuphea averaged across three planting dates (late April, early May, and late May) at seven locations. Lewis, Castana, and Calumet are in Iowa, USA and Lambertson, Morris, Crookston, and Roseau are in Minnesota, USA. Values within a year followed by the same letter were not different at the $P < 0.05$ level. From Forcella *et al.* (2005).



Cuphea PSR23 is not a highly efficient water user and requires a relatively large amount of water during its growth cycle for seed production. Its water use efficiency is about 1.5 to 2.0 kg ha⁻¹ of seed mm⁻¹ of water used (Sharratt and Gesch, 2004), which is at least two-times lower than that of other oilseeds such as soybean and canola (*Brassica napus* L.). Furthermore, PSR23 lacks a deep, well-structured root system that may make it prone to drought stress. Field studies at Morris, Minnesota show, that in a dry year, the use of irrigation can more than double PSR23 cuphea seed yields.

2.2. Best management practices

2.2.1. Planting and weed control

The seed of cuphea is small, disk shaped with an average weight of about 3 mg. Germination can be quite variable, and seedling vigor tends to be weak. Therefore, seeding depth is critical. We found that seed placed deeper than 1 cm can lead to poor stand establishment. Thus, the seedbed for cuphea must be well prepared with little excess crop residue on the surface. For planting cuphea, drill-seeding as shallow as possible works best. In west central Minnesota, the optimum time for planting is early to mid-May when soil moisture is relatively high and soil temperatures are above 10 °C (Gesch *et al.*, 2002a). Recently, coating cuphea seed with a clay-based material has facilitated more accurate planting by adding weight to the seed and making it more spherical.

A primary goal in developing cuphea production practices is to utilize equipment available to most farmers. Therefore, row-cropping equipment and techniques are being used. Plant spacing studies indicate that a population density in the range of 400,000 to 600,000 plants ha⁻¹ with an inter-row spacing of 40 to 60 cm (Gesch *et al.*, 2003) is near optimum. Because cuphea grows indeterminately, it has good yield compensation capacity. The more space allowed between plants, the more branching occurs and the greater the number of seed capsules and yield per plant (Gesch *et al.*, 2003). Good cuphea stands are achieved by mechanically seeding at a rate of about 9 kg ha⁻¹.

Optimum soil fertility for cuphea growth and seed yield has not been well researched. Preliminary evidence indicates that cuphea seed yield does not respond greatly to nitrogen application, but may increase with added sulfur. Most of our studies have been conducted on heavy loam soils with relatively high levels of residual fertilizer from previous crops. This probably explains why we have not detected yield responses to added fertilizers. Nevertheless, in all other agronomic experiments we routinely incorporate N, P, and K into the top 0.15 m of soil at rates of 112, 13, and 30 kg ha⁻¹, respectively, to guard against unexpected nutrient limitations.

The growth rate of cuphea tends to be slow during its vegetative development, but increases dramatically during anthesis, and canopy closure generally occurs soon after. For PSR23, flowering begins approximately 530 to 580 growing degree days (°C d; using a base temperature of 10 °C) after seeding (Gesch *et al.*, 2002a). Because of its slow vegetative growth, early season weed control can be problematic. Because cuphea is a dicotyledonous plant, a number of graminicides can be used to control weedy monocots (e.g., grasses). Sethoxydim at 0.3 kg ai ha⁻¹ has been successfully used for this purpose. Our greatest challenge has been to identify broadleaf herbicides that cuphea tolerates. Several broadleaf herbicides were tested and found to work well. Pre-plant incorporation of trifluralin or

ethalfuralin at 0.84 kg ai ha⁻¹, pre-emergence application of isoxaflutole at 0.08, and post-emergence application of mesotrione up to 0.27 kg ai ha⁻¹ controlled a wide range of broadleaf weeds without harming cuphea. However, for cuphea production to be successful over a wider geographical area, identification of additional herbicides is necessary.

2.2.2. Harvesting and seed drying

Because of cuphea's indeterminacy, once it begins flowering it can continue to flower up to two months. Additionally, even the most advanced PSR23 line is prone to seed shattering. Therefore, the timing of harvesting to achieve maximum yields is critical. In a 2-year field study conducted in west central Minnesota, the best time to harvest was in late September to early October U.S. (Gesch *et al.*, 2005) (Fig. 2). When planted in the spring, cuphea continues to grow until low temperatures kill it. Because of this, seed moisture can be quite high at harvest unless plants are first killed and desiccated by a hard frost, swathing, or application of a chemical desiccant. However, desiccation of plants due to a hard frost or chemical treatment tends to hasten seed shattering, and when left in the field too long, seed yields can decline rapidly (Fig. 2; mid to late Oct.). Thus far, combining directly has worked well for

Figure 2. Seed yield of PSR23 cuphea as a function of time of harvest. Values are means \pm SE. From Gesch *et al.* (2005).

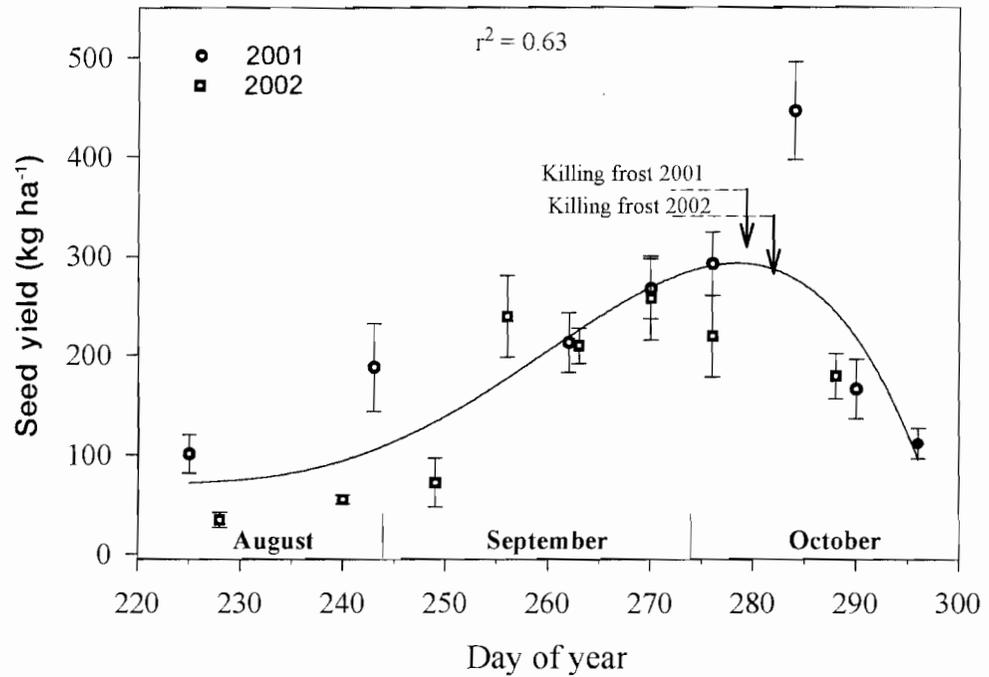
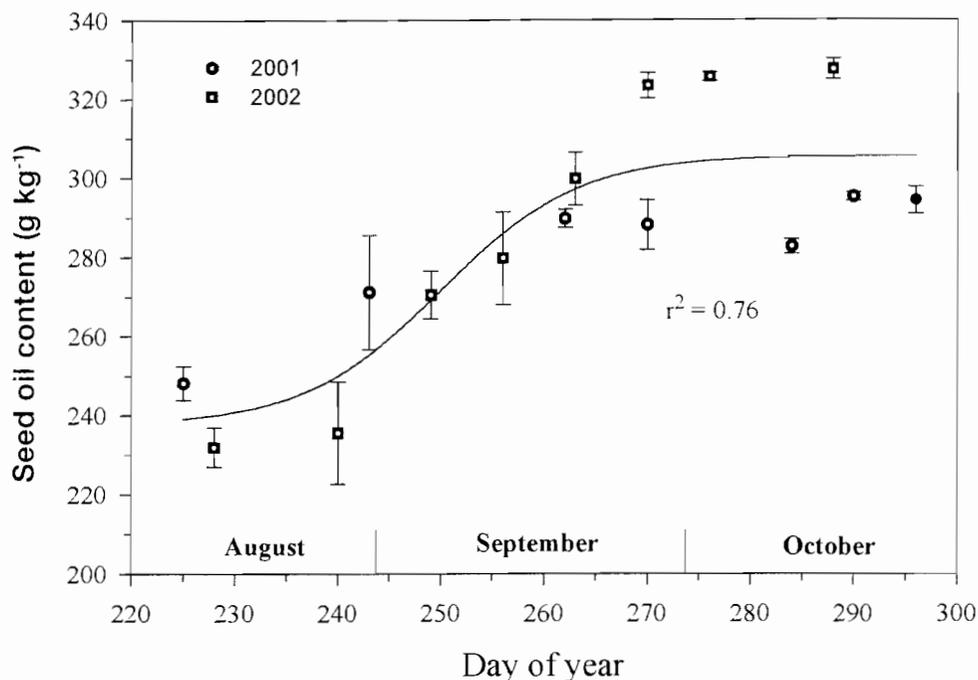


Figure 3. Seed oil content of PSR23 cuphea as a function of time of harvest. Arrows denote when the first killing frost occurred (day of year 278 in 2001 and 282 in 2002). Values are means \pm SE. From Gesch *et al.* (2005).



harvesting cuphea, although recent studies show that swathing has good potential. Paraquat and sodium chlorate, for desiccating plants, have also proven useful as harvest aids, but the crop should be harvested within approximately 7 d after treatment to avoid excessive shattering. Even with the use of swathing or chemical desiccation in the field, cuphea seed can contain as much as 30 to 40% water at harvest, thus requiring further drying. To accomplish this, a commercial batch-dryer designed for small seeded crops (e.g., canola) has been successfully used. For long-term storage of cuphea seed, its water content must be less than 10%.

Seed oil content similar to seed yield, also appears to be influenced by harvest date (Fig. 3). During a 2-year study, seed oil content responded sigmoidally, increasing substantially throughout early and mid September and reaching a plateau in late September (Fig. 3). In the northern Corn Belt region of the U.S., cuphea PSR23 typically begins flowering in late July and continues until inhibited by low temperatures in late September. However, the most extensive flower production tends to occur in mid August. Although no published data are available concerning the duration of seed development for domesticated cuphea (PSR23), preliminary evidence suggests that physiological maturity takes approximately 32 d (Marisol Berti, personal communication, 2004). If this is so, then an extensive flowering event in mid-August might explain why the greatest seed yield and oil content occur in late September (Figs. 2 & 3).

3. COMMERCIALIZATION PROJECT OF 2004

In terms of new crop development, we are discovering first-hand how difficult it is to make the leap from research to commercial production. However, with strong support from our industrial partners Procter and Gamble Company and Technology Crops International (TCI) a small-scale, on-farm commercialization project was initiated in 2004. TCI took the lead in contracting six farmers in west central Minnesota for cuphea production. Because the farmers involved in this project had no prior experience with cuphea, TCI and the USDA-Agricultural Research Service took active roles in cooperating with farmers to manage the production. Before the 2004 growing season, the farmers were informed about cuphea and the best management practices for its production. They were also provided a grower's guide. Each farmer grew 2 to 4 hectares for an overall total of 18.6 hectares. One of the farmers chose to do all of his own fieldwork, whereas the other five sub-contracted to have all their planting, herbicide application, and harvesting done at a similar time by one person. The seed used for planting was treated with a fungicide and coated with a clay-based material (Germain's Technology Group, Fargo, ND), for ease of planting. The farmer who chose to do his own fieldwork seeded with a 7.6 m wide press-drill that tended to place the seed too deep. Stand establishment in his field was about 309,000 per ha. The other five fields were planted with a 4.6 m wide no-till drill that seeded shallower and resulted in stands that ranged from 469,500 to 519,000 plants per ha.

Table 1. Land area of cuphea planted and harvested, and seed yield for the 2004 commercialization project conducted in west central Minnesota, USA

Farm	Hectares planted	Hectares harvested	Total seed wt. (kg @ 12% moisture)	Yield (kg/ha @ 12%)
1	4.05	4.05	1811	447
2	2.43	2.43	1007	415
3	2.02	0.91	678	744
4	4.05	3.44	1809	526
5	4.05	3.84	297	78
6	2.02	2.02	899	445
Totals	18.62	16.69	6501	Mean 443

Weather conditions during the 2004 growing season were cold and wet. The number of accumulated growing degree days (calculated with a 10°C base temperature) from May through September was 1083°C d, which is about 237°C d below normal. On 21 August, most areas within the study experienced frost. Despite these harsh conditions, cuphea PSR23 grew relatively well. For weed control, all fields were treated with ethalfluralin before planting and received a post-emergence application of mesotrione in early July. Generally, weed control was effective except for some field sites where certain weed species escaped. Biennial wormwood (*Artemisia biennis* Willd.) escaped control and three of the six fields had substantial infestations.



In late September, all fields were sprayed with a tank mix of paraquat and sodium chlorate to desiccate plants. The crop was relatively dry within 3 d after treatment, but because of a rain (43 mm) on the 4th d, harvesting was delayed an additional 5 to 10 days. Also, there were two hard frost events that occurred between desiccation treatment and harvest. Consequently, this resulted in substantial seed shatter and yield loss. Five of the fields were harvested with a John Deere (JD) 9400 combine and the other with a JD 7200, both having 7.6 m-wide heads. Seed yields ranged from 78 to 744 kg ha⁻¹ (Table 1). The lowest yielding field was also the last to be harvested (Farm 5; Table 1). A severe infestation of *Sclerotinia sclerotiorum* (white mold) was identified in this field, which undoubtedly contributed to the low yield, as did seed shattering from the delayed harvest. Because of various unforeseen problems, not all of the land area of cuphea planted could be harvested (Table 1). For instance, one farmer's field (Farm 3; Table 1) suffered damage from herbicide drift from an adjacent corn crop. Approximately 1.1 ha of damaged cuphea was cultivated and re-planted to soybean.

The moisture content of seed taken from the field averaged 38%, and therefore, was dried in a batch-style grain dryer designed for handling small-seeded crops. Because of limited dryer capacity and because all fields but one were harvested within 24 h, this stage of seed handling greatly restricted the timely processing of seed. Our targeted moisture content was approximately 12%, but after drying, it ranged from 9 to 15%. We later found that the seed lots stored above 10% sustained heating and mold growth and required re-drying to less than 10% moisture for proper storage.

4. CONCLUSIONS

Generally, the initial commercialization of cuphea in 2004 was successful and sufficient seed was generated to allow extensive seed and oil processing research and for on-farm production for the following year. For future large-scale production, a need exists to identify additional broadleaf weed control options. Furthermore, soil nutrient requirements for cuphea must be determined and characterized. Also, until more shatter-resistant and determinate lines of cuphea are developed, equipment and techniques designed for shatter-prone plants will be necessary for harvesting.

REFERENCES

- Cermak S.C., Isbell T.A., 2004.** Synthesis and physical properties of cuphea-oleic estolides and esters. *J. Am. Oil Chem. Soc.* 81, 297-303.
- Forcella F., Gesch R.W., Isbell T.A., 2005.** Seed yield, oil, and fatty acids of cuphea in the northwestern Corn Belt. *Crop Sci.* (in press).
- Geller D.P., Goodrum J.W., Knapp S.J., 1999.** Fuel properties of oil from genetically altered *Cuphea viscosissima*. *Ind. Crop Prod.* 9, 85-91.
- Gesch R.W., Forcella F., Barbour N., Phillips B., Voorhees W.B., 2002a.** Yield and growth response of *Cuphea* to sowing date. *Crop Sci.* 42, 1959-1965.

- Gesch R.W., Barbour N., Forcella F., Voorhees W.B., 2002b.** Cuphea growth and development: Responses to temperature. In: Janick, J., Whipkey, A. (Eds.), Trends in New Crops and New Uses. Proceedings of the 5th National Symposium of New Crops and New Uses Strength in Diversity, 10-13 Nov. 2001, Atlanta, GA. ASHS Press, Alexandria, VA, pp. 213-215.
- Gesch R.W., Forcella F., Barbour N., Phillips B., Voorhees W.B., 2003.** Growth and yield response of *Cuphea* to row spacing. Field Crops Res. 81, 193-199.
- Gesch R.W., Cermak S.C., Isbell T.A., Forcella F., 2005.** Seed yield and oil content of cuphea as affected by harvest date. Agron. J. (in press).
- Graham S.A., 1989.** *Cuphea*: A new plant source of medium-chain fatty acids. Crit. Rev. Food Sci. Nutrition 28, 139-173.
- Hirsinger F., 1985.** Agronomic potential and seed composition of *Cuphea*, an annual crop for lauric and capric seed oils. J. Am. Oil Chem. Soc. 62, 76-80.
- Knapp S.J., Crane J.M., 2000.** Registration of reduced seed shattering *Cuphea* germplasm PSR23. Crop Sci. 41, 299-300.
- Sharratt B.S., Gesch R.W., 2004.** Water use and root length density of *Cuphea* sp. Influenced by row spacing and sowing date. Agron. J. 96, 1475-1480.

