Weed Science, 49:628–634. 2001

Herbicide efficacy, leaf structure, and spray droplet contact angle among *Ipomoea* species and smallflower morningglory

Demosthenis Chachalis
Southern Weed Science Research Unit, USDA-ARS, P.O. Box 350, Stoneville, MS 38776
Current Address: Greek National Agricultural Research Foundation (NAGREF), Plant Protection Institute of Volos, P.O. Box 303, Volos 380 01, Greece

Krishna N. Reddy
Corresponding author. Southern Weed Science Research Unit, USDA-ARS, P.O. Box 350, Stoneville, MS 38776; kreddy@ars.usda.gov

C. Dennis Elmore
Application and Production Technology Research Unit, USDA-ARS, P.O. Box 36, Stoneville, MS 38776

Marcus L. Steele
Delta State University, Department of Physical Sciences, P.O. Box 3255, Cleveland, MS 38733

Greenhouse and laboratory studies were conducted to evaluate responses of ivyleaf morningglory, pitted morningglory, palmleaf morningglory, and smallflower morningglory to several herbicides in relation to leaf structure, epicuticular wax, and spray droplet behavior. Two- to four-leaf stage plants of each species were highly susceptible to acifluorfen, bentazon, bromoxynil, glufosinate, and glyphosate. However, at the five- to eight-leaf stage, these species were less susceptible, and control was herbicide specific. Spray droplets of these five herbicides had a higher contact angle on ivyleaf morningglory than the other three species with a few exceptions. Stomata and glands were present on both adaxial and abaxial leaf surfaces of all species, and palmleaf morningglory and smallflower morningglory had more of these than did the other two species. Trichomes were present on all species except palmleaf morningglory. Epicuticular wax mass was highest in ivyleaf morningglory (57 μg cm^{-2}) and lowest in smallflower morningglory (14 μg cm^{-2}). Wax consisted of homologous short-chain ($< C_{18}$) or long-chain ($> C_{20}$) hydrocarbons, alcohols, acids, and triterpenes. Smallflower morningglory waxes lacked short-chain length components. Triterpenes were absent in palmleaf morningglory and smallflower morningglory epicuticular waxes. Untriacontane (C_{31} hydrocarbon) and tridecanol (C_{30} alcohol) were common major long-chain components in waxes of all four species. Heptadecane (C_{17} hydrocarbon) and octanoic acid (C_{18}) were common major short-chain length wax components in pitted, ivyleaf, and palmleaf morningglory. In spite of some differences in leaf surface structures, wax mass, and wax components among the four species, there was no clear relationship between these parameters and herbicide efficacy.

Nomenclature: Acifluorfen; bentazon; bromoxynil; glufosinate; glyphosate; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. IPOHE; palmleaf morningglory, *Ipomoea wrightii* Gray IPOWR; pitted morningglory, *Ipomoea lacunosa* L. IPOLA; smallflower morningglory, *Jacquemontia tamnifolia* (L.) Griseb. IAQTA.

Key words: Spray droplet spread area.

Ivyleaf morningglory, pitted morningglory, palmleaf morningglory, and smallflower morningglory are listed among the 10 most common or troublesome weeds in the southern United States (Dowler 1998). These species cause interference with crops, increased lodging, reduced efficiency of mechanical harvest, and reduced yields (Barker et al. 1984). These species are among the five weeds that cause 66% of all cotton (*Gossypium hirsutum* L.) weed losses (Elmore et al. 1990). Full-season interference of annual *Ipomoea* species reduced yields of soybean (*Glycine max* L.) up to 70% (Eastman and Coble 1977; Oliver et al. 1976).

Leaf morphology varies considerably among morningglory species. It is generally known that ivyleaf morningglory has extensive trichomes on both leaf and stem, whereas palmleaf morningglory is smooth (Elmore et al. 1990). However, the effect of leaf surface characteristics of these species on herbicide efficacy has not been investigated.

Leaf surface structures affect the wetting and penetration behavior of foliar-applied herbicides (Hess 1985; Hull et al. 1982; McWhorter 1985; Wanamarta and Penner 1989). These leaf surface characteristics include the cuticle (epicuticular wax, cutin, and pectin), leaf age and development, leaf angle and position, and numbers of stomata and trichomes (Hess 1985; Hull et al. 1982; McWhorter 1985; Wanamarta and Penner 1989). Herbicide absorption is facilitated with either cuticular or stomatal infiltration, but no conclusive evidence indicates the comparative level of each route of penetration (Hess 1985; Wanamarta and Penner 1989).

The epicuticular wax appears to be an effective barrier to herbicide absorption. Removal of epicuticular wax with chloroform greatly increased glyphosate absorption in Coca [*Erythroxylum coca* var. *coca* (Lam.)] compared to plants with leaf epicuticular wax (Ferreira and Reddy 2000). Epicuticular leaf wax commonly occurs as a wax crystal deposition (Baker 1982; Hess 1985). Leaf wax contains primarily a variety of short- and long-chain hydrocarbons, alcohols, acids, esters, aldehydes, and triterpenes (Baker 1982). Wax is considered to be largely nonpolar and therefore hydrophobic, but variation exists among species. Hydrocarbons are considered highly hydrophobic, whereas alcohols and acids are relatively hydrophilic (Baker 1982). Information is lacking on the characterization of epicuticular wax in these species. The objective of this research was to determine the responses of ivyleaf, pitted, palmleaf, and smallflower morningglory to several herbicides in relation to leaf morphol-

ogy, epicuticular wax, and herbicide spray droplet characteristics.

Materials and Methods

General Greenhouse Procedures

Seeds were purchased locally from a commercial source[1] and were stored at 4 C prior to scarification with HCl to promote germination. Scarified seeds were placed in rectangular 6 by 7-cm containers filled with a mixture of soil (Bosket sandy loam, fine-loamy, mixed, thermic Mollic Hapludalfs) and potting soil[2] (1 : 1 by volume). Seedlings were transplanted (one plant per pot) approximately 1 wk after germination to 10-cm-diam pots containing the soil mixture above. Plants were grown in a greenhouse at 32/24 C (± 3 C) day/night temperature. Natural light was supplemented with sodium vapor lamps to provide a 14-h day length to prevent flowering. The soil mixture was surface irrigated as needed. Smallflower morningglory was transplanted 10 d before the other three species to synchronize plant size and herbicide application.

Herbicide Efficacy

Herbicide rates were selected to represent the manufacturers suggested use (1×) rates (Anonymous 2000). Commercial formulations of the following herbicides were used: acifluorfen, bentazon, bromoxynil, glufosinate, and glyphosate. A nonionic surfactant (X-77)[3] at 0.25% (v/v) was added to all herbicide spray solutions for uniformity. Spray solutions were applied using an indoor spray chamber equipped with an air-pressurized system equipped with 8002E nozzles at a volume of 190 L ha^{-1} at 140 kPa. Herbicides were selected to represent those used in transgenic (bromoxynil, glufosinate, and glyphosate) and in nontransgenic (acifluorfen and bentazon) corn (*Zea mays* L.), cotton, and soybean. The rates were as follows: acifluorfen 0.56 kg ai ha^{-1}, bentazon 1.1 kg ai ha^{-1}, bromoxynil 0.56 kg ai ha^{-1}, glufosinate 0.41 kg ai ha^{-1}, and glyphosate 1.1 kg ai ha^{-1}. Herbicides were applied to plants at two- to four-leaf stage and five- to eight-leaf stage. Bamboo sticks supported vining plants of five- to eight-leaf stage. Ivyleaf morningglory, pitted morningglory, and palmleaf morningglory plants reached two- to four-leaf and five- to eight-leaf stages approximately 10 and 15 d after transplanting, respectively. Smallflower morningglory plants reached two- to four-leaf and five- to eight-leaf stages within 20 and 25 d after transplanting, respectively. All species were sprayed at the same time. Herbicide activity was assessed 3 wk after treatment (WAT). Shoots of each species were clipped at the soil surface, oven dried (85 C for 2 d), and dry biomass recorded. Data were expressed as percent shoot dry biomass reduction (% control) as compared to that of nontreated plants. Treatments were arranged as a three-way factorial with herbicide, weed species, and growth stage as three factors in a randomized complete block design. Treatments were replicated four times, and the experiment was repeated. Data represent the average of the two experiments since no experiment by treatment interaction occurred. Control data were transformed using the log (x+1) transformation, where x was percent control. Transformed data were subjected to analysis of variance (ANOVA), and means were separated using Fisher's protected LSD test at $P = 0.05$.

Spray Droplet Contact Angle and Spread Area

Contact angle of herbicide spray droplets on leaves was measured on the adaxial surface of the second to fourth fully expanded leaf from the apical meristem as described by Chachalis et al. (2001). The leaves were selected daily at random just before measurement from five- to eight-leaf stage plants. The contact angles of both sides of a 1-μl droplet on a leaf surface were measured approximately 1 min after droplet application using a goniometer.[4] Each value was the mean of the contact angles of two sides of the droplet. For spread area measurements, the surface area of a 1-μl droplet on the leaf surface was measured approximately 5 min after the droplet application. Spread area was calculated using the formula πr^2, where r was the radius of the droplet. Preliminary trials showed that the 1-μl droplet on the leaf surface was rarely circular. Therefore, the radius was estimated as the mean of horizontal and vertical dimensions of the droplet. In some cases, spread was so great that the boundaries of the droplet were not clearly visible, and measurements were not possible. Contact angle and spread area measurements were replicated five times, and the experiment was repeated. Data were subjected to ANOVA, and means were separated using Fisher's Protected LSD test at $P = 0.05$.

Leaf and Stem Surface Structures

Five to eight leaves and stem were randomly sampled from five- to eight-leaf stage field-grown plants. Two leaf segments (approximately 20 mm^2) from the center of the leaf and stem segments (1 cm) were fixed for 12 h in 4% glutaraldehyde and rinsed three times with distilled water before dehydration in a graded ethanol series. Samples were critical point-dried[5] and mounted on aluminum stubs. Samples were gold-coated using a sputter coater[6] and examined using a scanning electron microscope.[7] Leaf and stem surfaces were photographed at the same magnification for all species, and individual structures were identified and counted. From each sample, two photographs were examined, and the study was replicated four times. The numbers of stomata, glands, and trichomes were counted as described previously (Chachalis et al. 2001; Elmore and Paul 1998).

Wax Extraction and Analysis

Epicuticular wax was extracted using the procedure previously described by Elmore et al. (1998). Fifty fully expanded leaves were randomly selected from five- to eight-leaf stage field-grown plants. Wax was extracted by immersing leaves for 10 s in 1 L HPLC-grade chloroform at room temperature. The chloroform/wax solution was filtered through analytical-grade filter paper, and the volume was reduced to approximately 20 ml in a rotary evaporator. The reduced chloroform/wax solution was transferred to a preweighed 25-ml glass scintillation vial. Chloroform was evaporated to dryness under a hood, and the vials were kept in a desiccator with silica gel blue for 14 d before wax mass was recorded. Wax mass was expressed as wax mass per unit leaf area. The total leaf area of leaf samples was determined

with a photoelectric leaf area meter.[8] Treatments were arranged in a randomized complete block design with three replications.

Wax analysis was performed as described by Chachalis et al. (2001). Each wax sample was silated for gas chromatography–mass spectrometry analysis by adding 50 μl hexamethyldisilazane, 100 μl heptane, and 10 μl pyridine and by placing it in the oven at 80 C for 12 h. A gas chromatograph[9] with a mass selective detector equipped with an autosampler was used. A 12 m by 0.2–mm inner diameter fused silicon capillary column coated with a 0.33-mm film of methyl silicone inserted directly into the ion source was used. The ion source was maintained at constant pressure of 10^{-5} Torr. Ultra-purity helium was the carrier gas. Operating temperatures were as follows: ion source, 200 C; injection port, 300 C; and transfer lines, 300 C. The temperature was ramped from 40 C to 125 C at a rate of 70 C min^{-1} and from 125 C to 300 C at the rate of 4 C min^{-1}. One microliter of the wax mixture was injected into the injection port set for a split ratio of approximately 62 to 1. Spectra were obtained at 70 eV, with mass range scanned from 50 to 650 daltons. The percent contribution of each major wax component to total wax was calculated using the peak area method (Kitson et al. 1996). Values represent the average of three chromatographs.

Results and Discussion

Herbicide Efficacy

Ivyleaf morningglory, pitted morningglory, palmleaf morningglory, and smallflower morningglory at the two- to four-leaf stage were highly susceptible (> 83% control) to acifluorfen, bentazon, bromoxynil, glufosinate, and glyphosate (Table 1). However, control of these species at five- to eight-leaf stage was variable. Ivyleaf and pitted morningglory at the five- to eight-leaf stage were less susceptible to glyphosate (< 38% control) and bentazon (< 65% control). The other three herbicides each provided greater than 74% control of ivyleaf morningglory and pitted morningglory. Control of five- to eight-leaf stage palmleaf morningglory was < 51% with bentazon and bromoxynil, 67% with glufosinate, and 80% or better with acifluorfen and glyphosate. Five- to eight-leaf stage smallflower morningglory control was 63% with bromoxynil and glyphosate and 70% or better with other three herbicides.

In previous studies, control of ivyleaf morningglory and pitted morningglory ranged from 25 to 94% with glyphosate (Askew and Wilcut 1999; Pline et al. 2000) and 27 to 99% with glufosinate (Krausz et al. 1999; Pline et al. 2000). As was the case with the results of this study, other results have indicated that ivyleaf morningglory and pitted morningglory were relatively less susceptible to glyphosate compared to the other two species (Mathis and Oliver 1980). Previous research has shown 90% or better control of ivyleaf morningglory and pitted morningglory with bromoxynil (Ketchersid and Chandler 1995) and 70% or better control with acifluorfen (Mathis and Oliver 1980; Palmer et al. 2000). Smallflower morningglory was highly susceptible (100% control) to bentazon, and ivyleaf morningglory was less susceptible to bentazon (Mathis and Oliver 1980).

TABLE 1. Control at 3 wk after treatment (WAT) of *Ipomoea hederacea* (ivyleaf morningglory), *I. lacunosa* (pitted morningglory), *I. wrightii* (palmleaf morningglory), and *Jacquemontia tamnifolia* (smallflower morningglory) plants treated with herbicides at the two- to four-leaf and five- to eight-leaf stages and herbicide spray droplet contact angle and spread area on leaf surface of five- to eight-leaf stage plants.[a,b]

		Control 3 WAT			
		Growth stage			
Species	Herbicide	2- to 4-Leaf	5- to 8-Leaf	Contact angle	Droplet spread
		%		degrees	mm^2
I. hederacea	Acifluorfen	100 a	87 ab	28	7.8
	Bentazon	84 b	65 c	36	7.9
	Bromoxynil	99 a	80 b	32	7.8
	Glufosinate	100 a	83 b	30	8.4
	Glyphosate	100 a	37 d	29	6.7
I. lacunosa	Acifluorfen	100 a	90 ab	16	9.8
	Bentazon	94 ab	42 c	23	9.0
	Bromoxynil	100 a	77 b	22	8.2
	Glufosinate	98 a	74 b	< 10	S[c]
	Glyphosate	100 a	38 c	26	8.2
I. wrightii	Acifluorfen	98 a	82 ab	25	10.5
	Bentazon	99 a	51 d	29	9.4
	Bromoxynil	90 ab	41 d	19	S[c]
	Glufosinate	100 a	67 b	< 10	S[c]
	Glyphosate	100 a	80 b	22	S[c]
J. tamnifolia	Acifluorfen	84 ab	70 b	23	10.5
	Bentazon	98 a	81 b	28	9.4
	Bromoxynil	100 a	63 bc	17	9.1
	Glufosinate	100 a	92 ab	< 10	S[c]
	Glyphosate	83 ab	63 bc	22	8.8
LSD (0.05)[d]				4	0.8

[a] Control data were nontransformed, whereas mean separation (for herbicide by growth stage within each species) was based on the LSD (0.05) value from transformed data.

[b] Herbicide rates were as follows: acifluorfen, 0.56 kg ai ha^{-1}; bentazon, 1.1 kg ai ha^{-1}; bromoxynil, 0.56 kg ai ha^{-1}; glufosinate, 0.41 kg ai ha^{-1}; and glyphosate, 1.1 kg ai ha^{-1}. A nonionic surfactant (X-77) at 0.25% (by volume) was added to all herbicides for uniformity.

[c] Excessive spreading of the 1-μl droplet after 5 min prevented measurement.

[d] LSD for comparing means within a column across all herbicides and species.

Spray Droplet Contact Angle and Spread Area

Acifluorfen, bentazon, bromoxynil, glufosinate, and glyphosate spray droplets had higher contact angle on ivyleaf morningglory than on the other three species, with the exception of acifluorfen on palmleaf morningglory and glyphosate on pitted morningglory (Table 1). Conversely, these herbicide spray droplets had lower spread area on ivyleaf morningglory than the other three species, with the exception of bromoxynil on pitted morningglory. Contact angles of herbicide spray droplets did not differ among pitted morningglory, palmleaf morningglory, and smallflower morningglory, with the exception of acifluorfen and bentazon on pitted morningglory. Bromoxynil and glyphosate spray droplets showed excessive spreading on palmleaf morningglory compared to the other three species. Glufosinate spray droplets on each species except ivyleaf morningglory had the lowest contact angle (< 10°) among herbicides and excessive spreading.

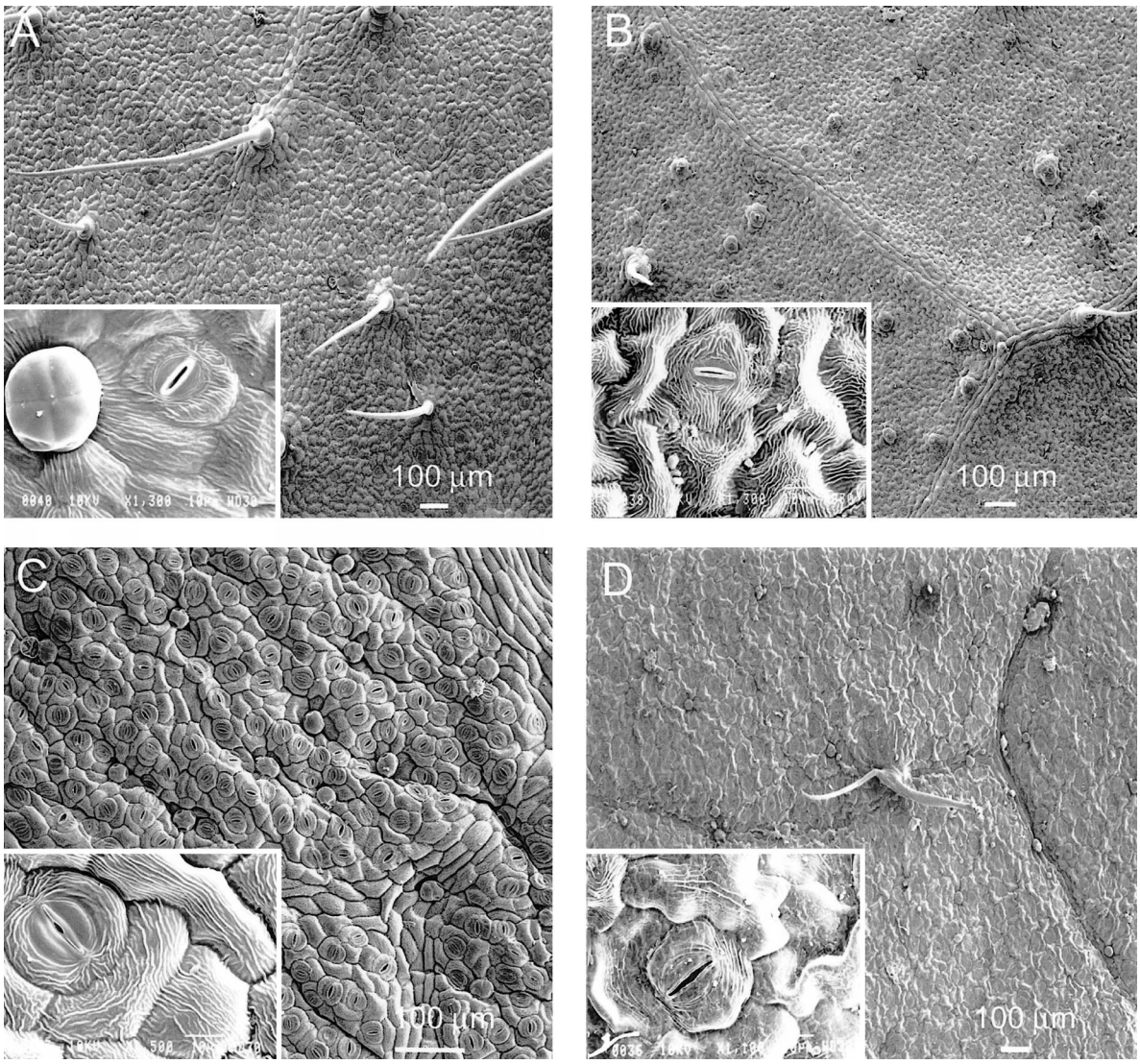

FIGURE 1. Scanning electron micrographs of the adaxial leaf surface of ivyleaf morningglory (A), pitted morningglory (B), palmleaf morningglory (C), and smallflower morningglory (D) at the five- to eight-leaf stage (bar = 100 µm). Small micrographs (inset) show a higher magnification of the adaxial leaf surface (bar = 10 µm).

Leaf and Stem Surface Structures

Leaf surface of these species was distinctly different (Figure 1). The adaxial leaf surface of ivyleaf morningglory had elongated trichomes; pitted morningglory and smallflower morningglory had short trichomes, whereas palmleaf morningglory lacked trichomes. The number of trichomes on both adaxial and abaxial leaf surfaces was highest for ivyleaf morningglory, compared to the other three species (Table 2). Trichomes were heavily silicated and were either unicellular (ivyleaf morningglory and pitted morningglory) or multicellular structures (smallflower morningglory).

The role of trichomes in relation to herbicide spread and absorption is complex and often contradictory. Trichomes could hinder wetting and spreading of spray droplets on the leaf surface, and droplets could shatter and bounce upon impact with trichomes (Hess et al. 1974; Hull et al. 1982). Hess et al. (1974) suggested that the length of trichomes is of lesser importance than trichomes density, since closely spaced trichomes may result in air pockets beneath the droplets that would prevent leaf surface contact. The high density of trichomes on the abaxial leaf surface only of ivyleaf morningglory diminishes the role of trichomes in herbicide spread and absorption in this species, since the herbicide spray droplet is primarily intercepted by the adaxial leaf surface. However, trichomes may provide a site of entry for herbicides, as shown with the use of fluorescent dyes (Benzing and Burt 1970). It was also our observation that trichomes showed a strong positive staining reaction to rhodamine dye that was tagged to glyphosate that indicated absorption (photos not presented).

All four species lacked crystalline wax deposition (Figure 1). Crystalline wax deposition is a predominant feature of leaf surface in many weed species (Harr et al. 1991) and has been considered the main barrier to cuticular herbicide penetration (Holloway 1970). The epidermal cells of ivyleaf morningglory, pitted morningglory and palmleaf morningglory had a close and dense arrangement of cuticular folds, one that is a common feature in many weed species (Harr et al. 1991), whereas the epidermal cells of smallflower morningglory were smoother (Figure 1).

TABLE 2. Leaf surface characteristics of the adaxial and abaxial surfaces of *Ipomoea hederacea* (ivyleaf morningglory), *I. lacunosa* (pitted morningglory), *I. wrightii,* (palmleaf morningglory), and *Jacquemontia tamnifolia* (smallflower morningglory) leaves at the five- to eight-leaf stages.

	Leaf surface characteristics					
	Stomata		Glands		Trichomes	
Species	Adaxial	Abaxial	Adaxial	Abaxial	Adaxial	Abaxial
	number mm^{-2}					
I. hederacea	56	172	2	3	4	10
I. lacunosa	34	99	1	3	2	2
I. wrightii	201	176	26	9	0	0
J. tamnifolia	156	239	6	8	1	1
LSD (0.05)	19		1		1	

Leaf glands were present in all four species (Figure 1; Table 2). Palmleaf morningglory and smallflower morningglory had relatively higher number of glands than the other two species, and consequently, these species had high spread area of herbicide spray droplet, with a few exceptions (Table 1). This result is in agreement with the suggestion that the presence of large numbers of glands might result in increased microroughness and hence higher spreading of herbicide droplet (McWhorter 1993).

Stomata number on the adaxial leaf surface was four to six times higher for palmleaf morningglory and smallflower morningglory than for ivyleaf morningglory or pitted morningglory (Table 2). However, on the abaxial leaf surface, stomata number was highest for smallflower morningglory, followed by ivyleaf morningglory or palmleaf morningglory, and was lowest for pitted morningglory. Herbicide infiltration through stomata has been reported (Wanamarta and Penner 1989); thus, palmleaf morningglory may have a higher level of stomatal infiltration of herbicide than do ivyleaf morningglory or pitted morningglory.

Stem morphology among the species was distinctly different (Figure 2). Ivyleaf morningglory stems were covered extensively with trichomes of various sizes, glands, and stomata, whereas stems of all other species lacked trichomes. Higher magnification of stems revealed that smallflower morningglory had fewer stomata compared to the other three species.

Leaf Wax Mass and Composition

Wax mass per unit leaf area was the highest in ivyleaf morningglory (57 $\mu g\ cm^{-2}$), followed by pitted morningglory (35 $\mu g\ cm^{-2}$), palmleaf morningglory (19 $\mu g\ cm^{-2}$), and smallflower morningglory (14 $\mu g\ cm^{-2}$) (Table 3). The epicuticular wax mass in most plant species varies from 10 to 200 $\mu g\ cm^{-2}$ (McWhorter 1993), but wax mass above 300 $\mu g\ cm^{-2}$ has been reported (Baker 1982). In general, the amount of wax and the spray droplet coverage were inversely related in ivyleaf morningglory and palmleaf morningglory (Tables 1 and 3). Previous results indicated that the amount of waxes had a positive (Holloway 1970), a negative (Hodgson 1973), or no (Al-Jaff et al. 1982) correlation with herbicide absorption.

Epicuticular wax in these four species consisted of homologous short-chain ($< C_{18}$) or long-chain ($> C_{20}$) lengths of straight-chain hydrocarbons, alcohols, acids, and triterpenes, with a clear distinction among species in terms of the wax composition (Table 3). Esters were absent in the four species studied, although they are a major component of epicuticular waxes in other species (Gülz et al. 1992; Mayeux and Wilkinson 1990). A major difference between smallflower morningglory and the other three species was the total absence of short-chain length components in the former species. Triterpenes were absent in palmleaf morningglory and smallflower morningglory epicuticular waxes. Numbers of individual hydrocarbons were the highest in palmleaf morningglory wax and the lowest in ivyleaf morningglory wax, which had the highest number of individual alcohols.

Although there was a clear difference among species in the presence of major wax components, some similarities were also apparent (Table 3). Untriacontane (C_{31} hydrocarbon) and tridecanol (C_{30} alcohol) were common major long-chain length components in all species. Heptadecane (C_{17} hydrocarbon) and octanoic (C_{18}) acid were common major short-chain length components in ivyleaf morningglory, pitted morningglory, and palmleaf morningglory.

Relative composition of the individual epicuticular wax components differed among the four species (Table 4). Wax of ivyleaf morningglory and pitted morningglory consisted of all four components (hydrocarbons, alcohols, acids, and triterpenes). Palmleaf morningglory leaf wax consisted of predominately hydrocarbons (58%), whereas smallflower morningglory wax consisted mostly of hydrocarbons (49%) and alcohols (46%). In general, alcohols and acids tend to be more hydrophilic than hydrocarbons. In this context, wax in palmleaf morningglory leaves tended to be relatively hydrophobic (hydrocarbons), but wax of ivyleaf morningglory and pitted morningglory leaves tended to be relatively hydrophilic (alcohols and acids).

Since few, if any, other convolvulaceae waxes have been completely analyzed, not all of our results can be compared to those reported previously for other species. Alcohols were often found to be the predominant wax component in the crude wax of many monocotyledonous species and dicotyledonous species (Baum et al. 1989), as was observed in smallflower morningglory wax extract in this study. Hydrocarbons ranged from 20 to 49% in redvine [*Brunnichia ovata* (Walt.) Shinners] and trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau] (Chachalis et al. 2001) and in *Euphorbia* species (Hemmers and Gülz 1986) at levels similar to those in ivyleaf morningglory, pitted morningglory, and smallflower morningglory in this study. It is interesting to note the very high hydrocarbon (58%) concentration in the palmleaf morningglory wax extract. Acids ranged from 0 to

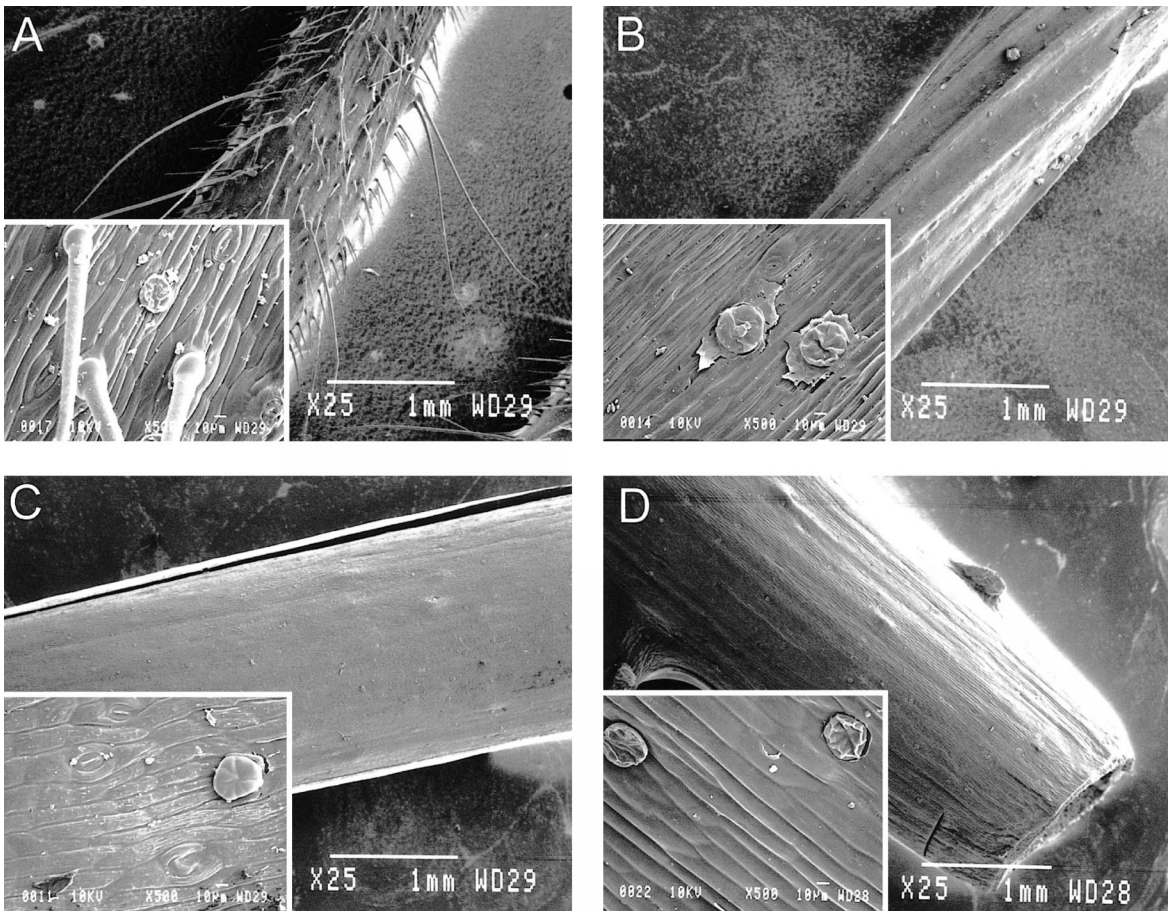

FIGURE 2. Scanning electron micrographs of the stem of ivyleaf morningglory (A), pitted morningglory (B), palmleaf morningglory (C), and smallflower morningglory (D) at the five- to eight-leaf stage (bar = 100 μm). Small micrographs (inset) show a higher magnification of the stem (bar = 10 μm).

TABLE 3. Epicuticular wax mass and composition of *Ipomoea hederacea* (ivyleaf morningglory), *I. lacunosa* (pitted morningglory), *I. wrightii* (palmleaf morningglory), and *Jacquemontia tamnifolia* (smallflower morningglory) leaves at the five- to eight-leaf stages.

Species	Wax mass	Wax composition[a]			
		Hydrocarbons	Alcohols	Acids	Triterpenes
	μg cm^{-2}				
I. hederacea	57	C_{17}* C_{31}*	C_{14} C_{26} C_{28} C_{30}* C_{32}	C_{14} C_{16}* C_{18}*	+*
I. lacunosa	35	C_{17}* C_{29}* C_{31}*	C_{14} C_{30}*	C_{16}* C_{18}* C_{20}	+*
I. wrightii	19	C_{17}* C_{29} C_{31}* C_{33}*	C_{28} C_{30}*	C_{16} C_{18}* C_{28}*	−
J. tamnifolia	14	C_{27} C_{29}* C_{31}*	C_{28} C_{30}* C_{32}*	C_{28} C_{30}*	−
LSD (0.05)	15				

[a] The number of carbons is indicated by the subscript; an asterisk indicates a major chromatograph peak, a minus (−) indicates absence, and a plus (+) indicates presence.

11% in other species (Chachalis et al. 2001; Hemmers and Gülz 1986), at levels somewhat lower than those in our study. Untriacontane has been reported as a major hydrocarbon in *Brassica* species (Hunt et al. 1976), honey mesquite (*Prosopsis glandulosa* Torr.) (Mayeux and Wilkinson 1990), *B. ovata,* and *C. radicans* (Chachalis et al. 2001) leaf waxes.

Our results indicated that the four morningglory species were highly susceptible to acifluorfen, bentazon, bromoxynil, glufosinate, and glyphosate at two- to four-leaf stage, but control of these species at five- to eight-leaf stage was

TABLE 4. Percent contribution of each major wax component to the total wax of *Ipomoea hederacea* (ivyleaf morningglory), *I. lacunosa* (pitted morningglory), *I. wrightii* (palmleaf morningglory), and *Jacquemontia tamnifolia* (smallflower morningglory) leaves at the five- to eight-leaf stages. Values were determined using the peak area method (Kitson et al. 1996).

Species	Wax component			
	Hydrocarbons	Alcohols	Acids	Triterpenes
	%			
I. hederacea	29	30	18	23
I. lacunosa	31	20	24	25
I. wrightii	58	19	23	0
J. tamnifolia	49	46	5	0
LSD (0.05)	7			

rather herbicide specific. Differences occurred in the number of glands, stomata, and trichomes as well as in wax mass and composition among these four species, but there was no clear relationship between herbicide efficacy and leaf surface structures, wax mass, or wax components.

Sources of Materials

[1] Seeds, Azlin Seed Service, P.O. Box 914, Leland, MS 38756.

[2] Jiffy Mix, Jiffy Products of America, Inc., Batavia, IL 60510.

[3] X-77 (a mixture of alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol), Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632.

[4] NRL C. A. Goniometer, Model 100-00-115, Rame-Hart, Inc., Mountain Lakes, NJ 07046.

[5] Balzers CPD 020, Balzers, 8 Sagamore Park Road, Hudson, NH 03051.

[6] Hummer X, Anatech, Ltd., 5510 Vine Street, Alexandria, VA 22310.

[7] Scanning electron microscope, JEOL-JSM 840 (USA), 11 Dearborn Road, Peabody, MA 10960.

[8] Portable area meter, Model LI-3000, Lamda Electronic Corp., 515 Broad Hollow Road, Melville, NY 11746.

[9] Gas chromatograph, Hewlett-Packard Model 5890, Hewlett-Packard Co., 9000 Executive Park Drive, Suite C-150, Knoxville, TN 37923.

Acknowledgments

We thank Rex N. Paul for assistance with scanning electron microscopy. We also thank Edwin Tullos, Phelesia Foster, and Jason Corbitt for technical assistance and Debbie Boykin for assistance with statistical analysis.

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Received May 30, 2000, and approved April 25, 2001.