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Carbon Dioxide Compensation Points of Flowering Plants[1]

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ABSTRACT

Carbon dioxide compensation points of several hundred species of monocotyledons and dicotyledons have been measured during the course of various experiments in our laboratory over a period of several years. These have been classified into two groups: high, compensation points of 40 μl/l or greater; and low, compensation points of 10 μl/l or less. They are listed alphabetically both by families and species for monocotyledons and dicotyledons. Only two species did not unequivocally fit into the above established groups. These were *Moricandia arvensis* (L.) DC., which had an average compensation point of 26 μl/l and *Panicum milioides* Nees ex Trin., which was variable, but most often equilibrated between 12 to 20 μl/l CO_2.

Since the discovery of the C_4-dicarboxylic acid (C_4) pathway for CO_2 fixation in higher plants (13, 17), there has been much interest in the distribution of the C_4 pathway in the plant kingdom. Species which have the C_4 pathway have CO_2 compensation points near 0 μl/l CO_2 in contrast to the Γ[3] of near 50 μl/l CO_2 for species which operate via the Calvin (C_3) cycle (8, 13, 18–20). CO_2 compensation points can be measured relatively easily; thus, they have provided a convenient means of classifying species for CO_2 fixation pathway. During the course of experiments extending over several years, we have made measurements of Γ on several hundred species. In response to numerous inquiries about specific species, we have prepared this manuscript listing all species on which we have made measurements of Γ.

MATERIALS AND METHODS

Seed for many of the grass species were obtained from United States Department of Agriculture Plant Introduction Stations and other locations as specified in Table I. Some of the dicotyledon species were collected locally; others were obtained from greenhouses operated by other departments at the University of Minnesota or were obtained from various botanical gardens and seed companies. These numerous sources for the dicotyledons have not been identified in Table II.

To determine Γ, a healthy, fully expanded leaf was excised under air-free water and placed in a glass test tube held vertically with the leaf base in about 5 ml of air-free water. This tube was placed in a closed circuit consisting of an air-circulating pump, a drying column, and an infrared gas analyzer. Either copper or glass tubing was used to join the components of the circuit. The tube was illuminated by 150-w incandescent lamps filtered by a least 10 cm of water. To maintain a constant leaf temperature the tube containing the leaf was submerged in a water bath. The water bath temperature differed somewhat for different experiments, ranging from 23 to 30 C, which affected the Γ of the C_3 species, but had little affect on the Γ of C_4 species.

In many experiments, air was circulated through the closed system containing the illuminated leaf until the CO_2 concentration in the air came to equilibrium. This equilibrium concentration was taken as Γ. Since the rate of change approached zero as the concentration of CO_2 in the closed system approached Γ, it often took 1 hr or more before an equilibrium was reached. Some of the results reported herein were obtained during surveys of several hundred species (4, 18). Often in those experiments, the absolute Γ was not determined; rather, to conserve time, measurements were discontinued when the concentration of CO_2 in the system came near to equilibrium. Therefore, if the rate of change of CO_2 in the system had slowed and the CO_2 concentration was less than 10 μl/l, the species was classified as low, and if it was greater than 40 μl/l, it was classified as high. Such measurements could be made in about 10 min.

RESULTS AND DISCUSSION

Tables I and II list the monocotyledons and dicotyledons, respectively, on which Γ measurements were made in this study, with each species classified as high (40 μl/l or greater) or low (10 μl/l or less).

Carbon dioxide compensation points have been reported in the literature for nearly 200 species in addition to those listed in Tables I and II. Table III summarizes these according to family and gives the reference where the information on individual species can be found.

Several workers have reported species with Γ between 10 and 40 μl/l (2, 12, 14). Chen *et al.* (2) found several species to have intermediate Γ, between 10 and 40 μl/l. Three of these were *Helianthus annuus* L., *Datura stramonium* L., and an *Ipomea* species which had Γ of 26, 26, and 28 μl/l CO_2, respectively. In repeated measurements at 29 C, Γ of 55 and 56 μl/l have been found in our laboratory for *Helianthus annuus* L. and *Datura stramonium* L. and 53 μl/l for *Ipomea aquatica* Forsk. Goldsworthy and Day (12) found *Lycopersicon esculentum* Mill. to have a Γ of 33 μl/l and it was 52 in our experiments. Heichel and Musgrave (14) have reported values of 9 to 26 μl/l for Γ of different maize genotypes. In a survey of 114 maize genotypes including many common to Heichel and Musgrave's experiment, we found a mean Γ of 1.3 μl/l with a standard deviation of 1.2 μl/l (21). The reason for differences between our results and those of others is unknown. We found remarkably little variation for Γ within a species, or for that matter, among high compensating species

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[3] Abbreviation: Γ: CO_2 compensation points.

Table I. *Classification of CO_2 Compensation Points of Monocotyledoneae*

Species[1]	Source[2]	I.D. No.[3]	r[4]
Amryllidaceae			
Agave americana L.	GH		H
Commelinaceae			
Zebrina pendula Schnizl.	GH		H
Cyperaceae			
Cyperus alternifolius L.	GH		H
C. esculentus L.	GH		L
C. papyrus L.	GH		L
Gramineae			
Aegilops caudata L.	NC	219868	H
A. columnaris Zhuk.	NC	170192	H
A. crassa Boiss.	NC	219958	H
A. cylindrica Host.	NC	172358	H
A. heldreichii Holzm.	NC	221899	H
A. ligustica (Savign.) Coss.	NC	170203	H
A. speltoides Tausch.	NC	219867	H
A. squarrosa L.	NC	220326	H
A. triaristata Willd.	NC	170194	H
A. triuncialis L.	NC	170197	H
A. umbellulata Zhuk.	NC	116294	H
Agropyron acutum R. & S.	NC	202727	H
A. buonapartis Th. Dur. & Schinz	NC	219970	H
A. campestre Godr. & Gren.	WR	276708	H
A. cristatum (L.) Gaertn.	NC	229574	H
A. desertorum (Fisch.) Schult.	NC	249143	H
A. elongatiforme Drobov	NC	207451	H
A. elongatum Host ex Beauv.	NC	98526	H
A. glaucum R. & S.	WR	302828	H
A. inerme (Scribn. & Smith) Rydb.	WR	236668	H
A. intermedium (Host) Beauv.	WR	172688	H
A. junceum (L.) Beauv.	WR	276566	H
A. kosanini Nabelek	NC	237636	H
A. latiglume (Scribn. & Smith) Rydb.	WR	232117	H
A. leptourum (Nevski) Grossheim	WR	229520	H
A. littorale Dum.	WR	277185	H
A. lolioides (Karel. & Kir.)	NC	223325	H
A. obtusiusculum Lange P. Candargy	NC	261099	H
A. orientale R. & S.	NC	219963	H
A. panormitanum Parl. ex Boiss.	NC	197569	H
A. pectiniforme R. & S.	NC	273734	H
A. pseudorepens Scribn. & Smith	WR	236676	H
A. pungens (Pers.) R. & S.	NC	229674	H
A. rigidum Beauv.	WR	276399	H
A. scabriglume (Hack.) Parodi	WR	238225	H
A. semicostatum (Steud.) Nees ex Boiss.	NC	269862	H
A. sibiricum (Willd.) Beauv.	NC	273736	H
A. smithii Rydb.	WR	236677	H
A. spicatum (Pursh) Scribn. & Smith	WR	232123	H
A. striatum (Steud.) P. Candargy	NC	207452	H
A. subulatum R. & S.	WR	204379	H
A. tenerum Vasey	WR	276711	H
A. trichophorum (Link) Richt.	NC	206259	H
A. violaceum Vasey	WR	276712	H
Agrostis alba L.	LO		H
A. hyemalis (Walt.) B.S.P.	LO		H
Alopecurus pratensis L.	VS		H
Andropogon cirratus Hack.	SR	216107	L
A. condensatus H.B. & K.	SR	203595	L
A. gerardi Vitman	VS		L
A. hassleri Hack.	SR	203721	L
A. hirtiflorus (Nees) Kunth	SR	228507	L
A. lateralis Nees	SR	309932	L
A. papillosus Hochst. ex A. Rich.	SR	221427	L
A. selloanus Hack.	SR	283001	L
A. ternatus Nees	SR	283002	L
A. virgatus Desv.	SR	309935	L
Anthephora pubescens Nees	SR	208282	L
Arrhenatherum elatius (L.) Presl	NC	251946	H
Arthraxon hispidus (Thunb.) Makino	SR	225986	L
Arundinella hirta L.	SR	263693	L
Avena abyssinica Hochst. ex A. Rich.	GH		H
A. barbata Brot.	GH		H
A. clauda Dur. in Duch.	GH		H
A. fatua L.	SR	202673	H
A. longiglumis Dur. in Duch.	GH		H
A. pilosa Bieb.	GH		H
A. sativa L.	LO		H
A. sterilis L.	GH		H
A. strigosa Schreb.	GH		H
A. ventricosa Balansa	GH		H
Bothriochloa alta (Hitchcock) Henrard	SR	204128	L
B. barbinodis Herter	SR	216060	L
B. decipiens (Hackel) C.E. Hubb.	SR	239152	L
B. ewartiana (Domin) C.E. Hubb.	SR	283004	L

TABLE I.—*Continued*

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
B. glabra (Roxb.) A. Camus	SR	209168	L
B. insculpta (Hochst.) A. Camus	SR	207977	L
B. intermedia (R. Br.) A. Camus	SR	173636	L
B. ischaemum (L.) Keng	SR	172373	L
B. laguroides (DC.) Herter	SR	283006	L
B. pertusa (Willd.) A. Camus	SR	212802	L
B. springfieldii (Gould) L. Parodi	SR	216163	L
Bouteloua curtipendula (Michx.) Torr.	SR	216219	L
B. filiformis (Fourn.) Griffiths	SR	255233	L
B. hirsuta Lag.	SR	255232	L
Brachiaria erucaeformis (J.E. Smith) Griseb.	SR	151838	L
B. laeta (Mez) A. Camus	SR	238236	L
B. ramosa Stapf	SR	180484	L
Bromus biebersteinii R. & S.	NC	172390	H
B. catharticus Vahl	VS		H
B. inermis Leyss.	LO		H
B. rigidus Roth	VS		H
B. tectorum L.	GH		H
Buchloe dactyloides (Nutt.) Engelm.	VS		L
Calamagrostis canadensis (Michx.) Beauv.	LO		H
Cenchrus biflorus Roxb.	SR	215637	L
C. ciliaris L.	SR	299513	L
C. myosuroides H.B. & K.	SR	216375	L
C. pauciflorus Benth.	VS		L
C. pilosus H.B. & K.	VS		L
C. setigerus Vahl	SR	193444	L
Chloris acicularis Lind. L. in MItch.	SR	238258	L
C. argentina (Hack.) Lillo & Parodi	SR	309959	L
C. canterai Arech.	SR	202366	L
C. caribaea Spreng.	SR	203626	L
C. distichophylla Lag.	SR	162637	L
C. gayana Kunth	SR	151008	L
C. inflata Link	SR	233832	L
C. pectinata Benth.	SR	238260	L
C. petraea Sw.	SR	204168	L
C. pilosa Schum. & Thonn.	SR	212386	L
C. polydactyla (L.) Sw.	SR	309963	L
C. pycnothrix Trin.	SR	194312	L
C. radiata (L.) Sw.	SR	309970	L
C. submutica H.B. & K.	SR	216386	L
C. truncata R. Br.	SR	212389	L
C. uliginosa Hack.	SR	203625	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
Chrysopogon montanus Trin.	SR	196210	L
C. serrulatus Trin.	SR	219580	L
Coelorachis cimicina (L.) Nees ex Jacks.	SR	206330	L
C. selloana (Hack.) A. Camus	SR	309987	L
Cymbopogon martini (Roxb.) W. Watson	SR	279582	L
Cynodon arcuatus F. & C. Presl	SR	287135	L
C. dactylon (L.) Pers.	SR	251809	L
Dactylis glomerata L.	GH		H
Dactyloctenium aegyptiacum Willd.	SR	215592	L
Danthonia montevidensis Hack. & Arech.	WR	284681	H
D. pilosa R. Br.	WR	212237	H
Deschampsia caespitosa (L.) Beauv.	WR	250961	H
Dichanthium annulatum Stapf	SR	180804	L
D. sericeum A. Camus	SR	213880	L
D. superciliatum A. Camus	SR	238285	L
Digitaria adscendens Henrard	SR	260639	L
D. argyrograpta Stapf	SR	198578	L
D. bicornis R. & S. ex Loud.	SR	175134	L
D. brownei Hughes	SR	238286	L
D. diagonalis Stapf	SR	209234	L
D. eriantha Steud.	SR	153403	L
D. eriostachya Mez	SR	204178	L
D. gazensis Rendle	Sr	258431	L
D. glauca Stent	SR	208379	L
D. horizontalis Willd.	SR	204179	L
D. iburua Stapf	SR	238288	L
D. ischaemum (Schreb.) Schreb. ex Muhl.	SR	196213	L
D. kilimandscharica Mez	SR	196343	L
D. milanjiana Stapf	SR	299061	L
D. pentzii Stent	SR	196346	L
D. phaeothrix Parodi	SR	162674	L
D. sanguinalis (L.) Scop.	LO		L
D. seriata Stapf	SR	208925	L
D. smutsii Stent	SR	208928	L
D. swazilandensis Stent	SR	238290	L
D. valida Stent	SR	196342	L
Echinochloa crusgalli (L.) Beauv.	NC	173754	L
E. frumentacea (Roxb.) W. F. Wight	NC	183332	L
E. haploclada Stapf	NC	226065	L
E. holubii Stapf	SR	207924	L
E. pyramidalis Hitchc. & Chase	NC	256044	L
E. spiralis Vasinger	NC	250392	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
Ehrharta calycina J.E. Smith	WR	208290	H
E. longiflora Sm.	WR	208941	H
Eleusine compressa Aschers. & Schweinf. ex Christensen			
	SR	275326	L
E. coracana (L.) Gaertn.	SR	205130	L
E. flagellifera Nees	SR	245371	L
E. floccifolia Spreng.	SR	196853	L
E. indica (L.) Gaertn.	SR	226270	L
E. jaegeri Pilger	SR	273888	L
E. multiflora Hochst.	SR	226067	L
E. tristachya (Lam.) Lam.	SR	203641	L
Elymus agropyroides Presl	WR	202147	H
E. angustus Trin. ex. Ledeb.	WR	271893	H
E. antarcticus Hook.	WR	286201	H
E. arenarius L.	WR	272126	H
E. canadensis L.	WR	232249	H
E. carolinianus Walt.	WR	272130	H
E. cinereus Scribn. & Merr.	WR	232252	H
E. crinitus Schreb.	WR	204577	H
E. dahuricus Turcz.	WR	221900	H
E. glaucus Buckl.	WR	232256	H
E. innovatus Beal	WR	232282	H
E. junceus Fisch.	WR	75737	H
E. paboanus Claus	WR	272135	H
E. virginicus L.	WR	272137	H
Eragrostis acutiflora Nees	WR	204196	L
E. acutiglumis Parodi	WR	203644	L
E. airoides Nees	WR	203656	L
E. atherstonei Stapf	WR	295687	L
E. bahiensis Schrad.	WR	203646	L
E. bicolor Nees	WR	190310	L
E. brasiliensis Nees	WR	203725	L
E. chalcantha Trin.	WR	276035	L
E. chariis (Schult.) Hitchc.	WR	217616	L
E. chloromelas Steud.	WR	156047	L
E. cilianensis (All.) Lutati	WR	202373	L
E. collocarpa K. Schum. ex Engl.	WR	209384	L
E. curvula (Schrad.) Nees	WR	156051	L
E. denudata Hack. ex Schinz	WR	208229	L
E. dielsii Pilg. ex Diels & Pritz.	WR	238301	L
E. diffusa Buckl.	WR	216408	L
E. ferruginea Beauv.	WR	295695	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
E. flaccida Lindm.	WR	203649	L
E. gummiflua Nees	WR	299931	L
E. heteromera Stapf	WR	208129	L
E. horizontalis Peter	WR	299934	L
E. intermedia Hitchc.	WR	216398	L
E. lappula Nees	WR	209187	L
E. lehmanniana Nees	WR	203350	L
E. margaritacea Stapf	WR	208131	L
E. mexicana (Hornem.) Link	WR	216414	L
E. nigra Nees ex Steud.	WR	217610	L
E. obtusa Munro	WR	208166	L
E. oxylepis (Torr.) Torr.	WR	295692	L
E. papposa Steud.	WR	219589	L
E. patentissima Hack. ex Schinz	WR	299949	L
E. plana Nees	WR	208293	L
E. poaeoides Beauv. ex R. & S.	WR	180835	L
E. polytricha Nees	WR	202443	L
E. rigidior Pilger	WR	209188	L
E. robusta Stent	WR	207951	L
E. rufescens R. & S.	WR	164024	L
E. secundiflora Presl	WR	216405	L
E. starosselskyi Grossheim	WR	211029	L
E. stenophylla Hochst.	WR	213255	L
E. superba Peyr.	WR	156049	L
E. tremula Hochst.	WR	220220	L
E. trichodes (Nutt.) Wood	WR	276056	L
E. truncata Hack.	WR	299962	L
E. unioloides (Retz.) Nees	WR	217615	L
E. virescens Presl	WR	203652	L
Eremopyrum buonapartis (Spreng.) Nevski	NC	219962	H
E. distans (K. Koch) Nevski	NC	193264	H
E. orientale Jaub. & Spach	NC	220568	H
Euchlaena mexicana Schrad.	NC	162704	L
Festuca megalura Nutt.	LO		H
F. rubra L.	LO		H
Helictotrichon hookeri (Scribn.) Henr.	NC	234878	H
Heteropogon contortus Beauv. ex R. & S.	SR	213517	L
Hordeum bogdani Wilensky	WR	269406	H
H. brevisubulatum Link	WR	229447	H
H. bulbosum L.	NC	204579	H
H. comosum Presl	WR	264405	H
H. compressum Griseb.	WR	283380	H

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
H. hystrix Roth	NC	203462	H
H. jubatum L.	NC	234683	H
H. marinum Huds.	NC	223324	H
H. spontaneum Koch	NC	219796	H
H. stebbinsii Covas	NC	206686	H
H. vulgare L.	LO		H
Hyparrhenia hirta (L.) Stapf	SR	203356	L
H. rufa (Nees) Stapf	SR	200554	L
Iseilema membranacea Domin	SR	240840	L
I. vaginiflora Domin	SR	257762	L
I. wightii Anderss.	SR	213524	L
Koeleria cristata (L.) Pers.	NC	229463	H
K. phleoides (Vill.) Pers.	WR	223268	H
K. setacea DC.	NC	234759	H
K. valesiaca Gaud.	WR	287842	H
Leersia oryzoides (L.) Sw.	GH		H
Leptochloa dubia (H.B. & K.) Nees	SR	204205	L
L. fascicularis (Lam.) A. Gray	LO		L
L. fusca Kunth	SR	208222	L
Lolium multiflorum Lam.	NC	162455	H
L. perenne L.	NC	170521	H
L. persicum Boiss. & Hohen.	NC	163283	H
L. rigidum Gaud.	NC	250803	H
L. strictum Presl	WR	204080	H
L. temulentum L.	NC	165555	H
Muhlenbergia racemosa (Michx.) B.S.P.	LO		L
Panicum amarulum Hitchc. & Chase	MS	2191	L
P. ambiguum Haussk.	SR	271024	L
P. anceps Michx.	TX	PMT1262	L
P. antidotale Retz.	NM	A-16851	L
P. bergii Arech.	SR	285216	L
P. bisulcatum Thunb.	NC	286485	H
P. capillare L.	NC	220025	L
P. clandestinum L.	MI	MS 1737	H
P. coloratum Cav.	SR	300628	L
P. cymbiforme D.K. Hughes	NC	238344	L
P. decompositum R. Br.	AU	Q196	L
P. deustum Thunb.	SR	208244	L
P. dichotomiflorum Michx.	LO		L
P. effusum R. Br.	AU	C1181	L
P. firmulum Hitchc. & Chase	NM	NM-270	L
P. hallii Vasey	NM	A-8002	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
P. havardii Vasey	NM	NM-528	L
P. hemitomon Schult.	GA	1585	H
P. laevifolium Hack.	SR	209196	L
P. lanipes Mez	NC	238346	L
P. larcomianum D.K. Hughes	AU	Q270	L
P. longijubatum Stapf	SR	189614	L
P. makarikariense	SR	184776	L
P. maximum Jacq.	NM	P-15578	L
P. miliaceum L.	NC	163298	L
P. milioides Nees ex Trin.	SR	285219	L[5]
P. minus Nash	NM	A-11966	L
P. molle Michx.	SR	306277	L
P. obtusum H.B. & K.	TX	PMT1023	L
P. oligosanthes Schult.	LO		H
P. pacificum Hitchc. & Chase	SP	1161	H
P. plenum Hitchc. & Chase	TX	PMT1266	L
P. polygonatum Schrad	SR	203869	L
P. praecocius Hitchc. & Chase	LO		H
P. prolutum F. Muell.	NC	208687	L
P. queenslandicum Domin	SR	257775	L
P. reverchoni Vasey	TX	PMT771	L
P. stapfianum Fourc.	NC	300058	L
P. texanum Buckl.	MI	MS358	L
P. trachyrhachis Benth.	AU	C974	L
P. trichanthum Nees	SR	206329	H
P. turgidum Forsk.	NC	221079	L
P. virgatum L.	NC	204907	L
P. whitei J. M. Black	AU	Q228	L
P. wilcoxianum Vasey	LO		H
Pappophorum bicolor Fourn.	SR	216527	L
Paspalum almum Chase	SR	284523	L
P. boscianum Flüegge	SR	310046	L
P. brunneum Mez	SR	303960	L
P. ciliatifolium Michx.	LO		L
P. conjugatum Bergius	SR	282801	L
P. dilatatum Poir.	SR	202188	L
P. distichum L.	SR	276244	L
P. geminiflorum Steud.	SR	303985	L
P. intermedium Munro ex Morong	SR	310111	L
P. juegensii Hack.	SR	303994	L
P. mandiocanum Trin.	SR	303996	L
P. nicorae Parodi	SR	304004	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
P. notatum Flüegge	SR	296005	L
P. paniculatum L.	SR	304006	L
P. paucispicatum Vasey	SR	304014	L
P. platyphyllum Griseb.	SR	162905	L
P. plicatulum Michx.	SR	276253	L
P. polystachyum Kuntze	SR	224996	L
P. pubiflorum Rupr. ex Fourn.	SR	304147	L
P. pumilum Nees	SR	310250	L
P. quadrifarium Lam.	SR	283022	L
P. rojasii Hack.	SR	282806	L
P. scrobiculatum L.	SR	197275	L
P. umbrosum Trin.	SR	203755	L
P. urvillei Steud.	SR	202299	L
P. virgatum L.	SR	196482	L
P. yaguaronense Henr.	SR	304055	L
Pennisetum ciliare (L.) Link	VS		L
P. flaccidum Griseb. in Goett.	SR	220606	L
P. glaucum (L.) R. Br.	SR	250215	L
P. macrourum Trin.	SR	273257	L
P. massaicum Stapf	SR	214061	L
P. orientale Rich.	SR	218097	L
P. pedicellatum Trin.	SR	213275	L
P. polystachyum Schult.	SR	189347	L
P. spicatum R. & S.	SR	295126	L
P. typhoideum Rich.	SR	300088	L
Phalaris arundinacea L.	LO		H
Phleum pratense L.	LO		H
Poa annua L.	LO		H
P. pratensis L.	LO		H
P. trivialis L.	VS		H
Saccharum officinarum L.	GH		L
Secale montanum Guss.	NC	240286	H
S. vavilovii Grossheim	NC	253957	H
Setaria adhaerens (Forsk.) Chiov.	SR	216575	L
S. almaspicata de Wit	SR	208946	L
S. argentina Herrm.	NC	284689	L
S. faberii Herrm.	GH		L
S. glauca (L.) Beauv.	NC	204629	L
S. holstii Herrm.	SR	208300	L
S. italica (L.) Beauv.	NC	173103	L
S. lutescens (Weigel) Hubb.	NC	223293	L
S. neglecta de Wit	NC	300110	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
S. pallidifusca Stapf & C.E. Hubb.	SR	195037	L
S. palmifolia (Koen.) Stapf	NC	239197	L
S. phanerococca Stapf	SR	299072	L
S. sphacelata (Schum.) Stapf & C.E. Hubb.	NC	213277	L
S. verticillata (L.) Beauv.	NC	204626	L
S. viridis (L.) Beauv.	NC	204624	L
Sitanion hystrix (Nutt.) J.G. Smith	WR	232353	H
Sorghastrum nutans (L.) Nash	LO		L
S. pellitum Parodi	SR	310306	L
Sorghum almum Parodi	NC	190579	L
S. arundinaceum R. & S.	SR	302113	L
S. bicolor Moench	NC	305081	L
S. caffrorum Beauv.	SR	291381	L
S. caudatum Stapf	SR	302131	L
S. controversum (Steud.) Snowden	SR	302136	L
S. dochna (Forsk.) Snowden	SR	302137	L
S. drummondii Nees	SR	302141	L
S. gambicum Snowden	SR	302150	L
S. halepense (L.) Pers.	SR	209217	L
S. hewisonii (Piper) Longley	SR	302173	L
S. japonicum (Hackel) Roshev.	SR	302174	L
S. nigricans Hort. ex R. & S.	SR	302177	L
S. saccharatum Moench	SR	302198	L
S. sudanense (Piper) Stapf	NC	220969	L
S. technicum (Koern.) Battand. & Trab.	SR	209792	L
S. verticilliflorum Stapf	NC	300117	L
S. virgatum (Hack.) Stapf	SR	302232	L
Spartina pectinata Link	LO		L
Sporobolus capensis Kunth	WR	258455	L
S. contractus Hitchc.	WR	241073	L
S. cryptandrus (Torr.) A. Gray			L
S. elongatus R. Br.	WR	194864	L
S. fimbriatus Nees	WR	198597	L
S. helvola Th. Dur. & Schinz	WR	219620	L
S. indicus (L.) R. Br.	WR	310309	L
S. ioclados Nees	WR	300124	L
S. jacquemontii Kunth	WR	310012	L
S. phyllotrichus Hochst.	WR	226098	L
S. poiretii (R. & S.) Hitchc.	WR	310312	L
S. pyramidatus (Lam.) Hitchc.	WR	196075	L
S. usitatus Stent	WR	198598	L
Trichachne californica (Benth.) Chase	SR	216617	L

TABLE I.—*Continued*

Species[1]	Source[2]	I.D. No.[3]	r[4]
Trichloris crinita (Lag.) Parodi	SR	306285	L
Tricholaena monachne Stapf & C.E. Hubb.	NC	166381	L
T. repens (Willd.) Hitchc.	SR	186430	L
Trisetum flavescens (L.) Beauv.	WR	235458	H
Triticum aestivum L.	LO		H
T. dicoccum Schrank	GH		H
T. durum Desf.	GH		H
T. monococcum L.	GH		H
T. vulgare Vill.	GH		H
Urochloa mosambicensis (Hackel) Dandy	SR	209228	L
U. pullulans Stapf	SR	208954	L
Vaseyochloa multinervosa (Vasey) Hitchc.	SR	216663	L
Vetiveria zizanioides (L.) Nash	SR	302300	L
Zea mays L.	LO		L
Zizania aquatica L.	GH		H
Liliaceae			
Allium cepa L.	GH		H
A. fistulosum L.	GH		H
A. odorum L.	GH		H
A. sativum L.	GH		H
A. schoenoprasum L.	GH		H
Asparagus officinalis L.	LO		H
Chlorophytum capense (L.) Voss	GH		H
Hymenocallis occidentalis Kunth	LO		H
Lilium longiflorum Thunb.	GH		H
Typhaceae			
Typha angustifolia L.	LO		H
T. latifolia L.	LO		H

[1] Much of the seed came with an identification number and genus and species names but with no authority listed. We have listed the species names with an authority, using Hitchcock (15), Index Kewensis, and the Gray Herbarium Card Index as the sources of the authorities.

[2] Sources of the species are: AU, Division of Plant Industries, CSIRO, Canberra City, A.C.T., Australia; GA, Americus Plant Materials Center, P.O. Box 680, Americus, Ga. 31709; GH, obtained in various University of Minnesota greenhouses; LO, collected locally; MI, Soil Conservation Service, P.O. Box D, Coffeeville, Miss. 38922; NC, North Central Regional Plant Introduction Station, Ames, Iowa 50510; NM, Plant Materials Center, Route 1, Box 28, Los Lunas, N. M. 87031; SP, Dr. Richard Spellenberg, Department of Biology, Box 3AF, Las Cruces, N. M. 88001; SR, Southern Regional Plant Introduction Station, Experiment, Ga. 30212; TX, Soil Conservation Service, James E. "Bud" Smith, Plant Materials Center, Knox City, Texas 79529; VS, Valley Seed Service, 2007 Alameda Avenue, Davis, Calif. 95616; WR, Western Regional Plant Introduction Station, Pullman, Wash. 26421.

[3] Identification numbers are the catalogue numbers assigned to the seed by the supplier.

[4] Species classified as low (L) had compensation points of 10 μl/l CO_2 or less; those classified as high (H) had compensation points of 40 μl/l or greater.

[5] Compensation point actually greater than 10 μl/l CO_2; see text.

Table II. *Classification of CO_2 Compensation Points of Dicotyledoneae*

Species[1]	r[2]
Acanthaceae	
Fittonia verschaffeltii Coem.	H
Graptophyllum pictum Griff.	H
Aceraceae	
Acer negundo L.	H
A. platanoides L.	H
A. saccharum L.	H
Aizoaceae	
Mesembryanthemum cordifolium L.	H
M. criniflorum L.	H
M. crystallinum L.	H
M. tricolorum Haw.	H
Mollugo verticillata L.	H
Trianthema portulacastrum L.	L
T. triquetra Rottl. & Willd.	L
Alismaceae	
Sagittaria latifolia Willd.	H
Amaranthaceae	
Amaranthus albus L.	L
A. graecizans L.	L
A. hybridus L.	L
A. powellii S. Wats.	L
A. retroflexus L.	L
A. spinosus L.	L
Celosia argentea L.	H
Gomphrena globosa L.	L
Anacardiaceae	
Rhus glabra L.	H
R. radicans L.	H
R. typhina L.	H
Apocynaceae	
Apocynum androsaemifolium L.	H
Nerium oleander L.	H
Aquifoliaceae	
Ilex verticillata (L.) Gray	H
Araceae	
Pistia stratiotes L.	H
Araliaceae	
Hedera helix L.	H
Asclepiadaceae	
Asclepias ovalifolia Dcne.	H

TABLE II.—*Continued*

Species[1]	r[2]
A. syriaca L.	H
A. tuberosa L.	H
Balsaminaceae	
Impatiens balsamina L.	H
Begoniaceae	
Begonia semperflorens Link & Otto	H
Berberidaceae	
Berberis pruinosa Franch.	H
Mahonia aquifolium Nutt.	H
Bignoniaceae	
Catalpa speciosa Warder	H
Boraginaceae	
Heliotropium arborescens L.	H
H. europaeum L.	H
H. parviflorum L.	H
Cactaceae	
Pereskia aculeata Mill.	H
Campanulaceae	
Campanula rotundifolia L.	H
Capparidaceae	
Gynandropsis speciosa DC.	L
Caprifoliaceae	
Lonicera dioica L.	H
Sambucus pubens Michx.	H
Viburnum lentago L.	H
V. trilobum Marsh.	H
Caryophyllaceae	
Dianthus caryophyllus L.	H
Lychnis alba Mill.	H
L. chalcedonica L.	H
Lycium chinense Mill.	H
Silene cucubalus Wibel	H
S. pendula L.	H
Stellaria media (L.) Cyrillo	H
Tunica saxifraga Scop.	H
Chenopodiaceae	
Atriplex breweri Wats.	L
A. glabriuscula Edmondston	H
A. nummularia Lindl.	L
A. patula L.	H
A. rosea L.	L
A. semibaccata Moq.	L

TABLE II.—*Continued*

Species[1]	r[2]
Chenopodium album L.	H
Kochia scoparia (L.) Roth	L
Salsola kali L.	L
Spinacia oleracea L.	H
Compositae	
Achillea millefolium L.	H
Ambrosia trifida L.	H
Arctium minus (Hill) Bernh.	H
Bidens vulgata Greene	H
Centaurea cyanus L.	H
C. dealbata Willd.	H
C. gymnocarpa Moris & De Not.	H
C. jacea L.	H
C. macrocephala Puschk.	H
C. maculosa Lam.	H
C. moschata L.	H
C. pulcherrima Willd.	H
Chrysanthemum morifolium Ramat.	H
C. spatiosum Bailey	H
Cirsium discolor (Muhl.) Spreng.	H
C. vulgare (Savi) Tenore	H
Eupatorium altissimum L.	H
Galinsoga ciliata (Raf.) Blake	H
G. parviflora Cav.	H
Grindelia squarrosa (Pursh) Dunal	H
Helianthus annuus L.	H
Iva xanthifolia Nutt.	H
Lactuca pulchella (Pursh) DC.	H
L. scariola L.	H
Liatris ligulistylis (Nels.) K. Schum.	H
Matricaria chamomilla L.	H
Solidago memoralis Ait.	H
S. rigida L.	H
Tagetes erecta L.	H
Taraxacum officinale Weber	H
Zinnia elegans Jacq.	H
Convolvulaceae	
Convolvulus sepium L.	H
Ipomoea aquatica Forsk.	H
Cornaceae	
Cornus alternifolia L.	H
Corylaceae	
Corylus americana Walt.	H

TABLE II.—*Continued*

Species[1]	r[2]
Ostrya virginiana (Mill.) K. Koch	H
Crassulaceae	
Kalanchoe blossfeldiana Poelln.	H
K. daigremontiana Hamet & Perrier.	H
Cruciferae	
Barbarea vulgaris R. Br.	H
Berteroa incana DC.	H
Brassica napobrassica Mill.	H
B. oleracea L.	H
B. rapa L.	H
B. septiceps Bailey	H
Capsella bursa-pastoris Medic.	H
Cheiranthus cheiri L.	H
Crambe maritima L.	H
Farsetia clypeata R. Br.	H
Moricandia arvensis (L.) DC.	H[3]
Raphanus sativus L.	H
Thlaspi arvense L.	H
Cucurbitaceae	
Cucumis melo L.	H
Dipsacaceae	
Dipsacus fullonum L.	H
Scabiosa africana L.	H
S. atropurpurea L.	H
S. graminifolia L.	H
S. prolifera Mazziari	H
S. ucranica L.	H
Droseraceae	
Dionaea muscipula Ellis	H
Elaeagnaceae	
Elaeagnus angustifolia L.	H
Ericaceae	
Arctostaphylos uva-ursi (L.) Spreng.	H
Rhododendron mucronulatum Turcz.	H
Euphorbiaceae	
Euphorbia corollata L.	H
E. cyparissias L.	H
E. dentata Michx.	H
E. esula L.	H
E. forbesii Sherff	L
E. geyeri Engelm.	L
E. glyptosperma Engelm.	L
E. heterophylla L.	H
E. hexagona Nutt.	H
E. lactea Haw.	H
E. maculata L.	L
E. marginata Pursh	H
E. missurica Raf.	L
E. pulcherrima Willd.	H
E. serpyllifolia Pers.	L
E. splendens Boj.	H
E. supina Raf.	L
Ricinus communis L.	H
Fagaceae	
Quercus ellipsoidalis E. J. Hill	H
Q. macrocarpa Michx.	H
Q. muehlenbergii Engelm.	H
Geraniaceae	
Pelargonium peltatum Soland.	H
P. zonale L'Herit.	H
Gesneriaceae	
Saintpaulia ionantha Wendl.	H
Ginkgoaceae	
Ginkgo biloba L.	H
Hippocastanaceae	
Aesculus glabra Willd.	H
Hydrophyllaceae	
Ellisia nyctelea L.	H
Juglandaceae	
Juglans nigra L.	H
Labiatae	
Coleus thrysoideus Baker	H
Leonurus cardiaca L.	H
Monarda punctata L.	H
Perilla frutescens (L.) Britt.	H
Prunella vulgaris L.	H
Salvia splendens Ker	H
Thymus vulgaris L.	H
Leguminosae	
Amopha canescens Pursh	H
Caragana arborescens Lam.	H
Crotalaria axillaris Dryand.	H
C. capensis Jacq.	H
C. crassipes Hook.	H

TABLE II.—*Continued*

Species[1]	r[2]
C. dissitiflora Benth.	H
C. juncea L.	H
C. mitchellii Benth.	H
C. mysorensis Roth	H
C. retusa L.	H
Dolichos lablab L.	H
Genista aethnensis DC.	H
G. horrida DC.	H
G. monosperma Lam.	H
G. monspessulana (L.) L.A.S. Johnson	H
G. pilosa L.	H
G. radiata Scop.	H
G. sagittalis L.	H
G. tinctoria L.	H
Gleditsia triacanthos L.	H
Glycine max (L.) Merr.	H
Indigofera australis Willd.	H
I. cylindrica DC.	H
I. cytisoides L.	H
I. dosua Buch.-Ham.	H
I. filifolia Thunb.	H
I. frutescens L.	H
I. kirilowii Maxim.	H
I. orthocarpa Presl	H
I. splendens Ficalho & Hiern	H
I. viscosa Lam.	H
Lespedeza capitata Michx.	H
L. leptostachya Engelm.	H
Lotus corniculatus L.	H
L. hispidus Desf.	H
L. ornithopodioides L.	H
L. requienii Hort.	H
L. uliginosus Schkuhr	H
Medicago sativa L.	H
Mimosa pudica L.	H
Pisum sativum L.	H
Robinia pseudo-acacia L.	H
Spartium junceum L.	H
Vicia angustifolia Reichard	H
V. faba L.	H
V. sativa L.	H
Linaceae	
Linum usitatissimum L.	H

TABLE II.—*Continued*

Species[1]	r[2]
Lythraceae	
Lythrum salicaria L.	H
Malvaceae	
Abutilon theophrasti Medic.	H
Malva neglecta Wallr.	H
Menispermaceae	
Menispermum canadense L.	H
Moraceae	
Cannabis sativa L.	H
Ficus lyrata Warb.	H
Morus alba L.	H
Nyctaginaceae	
Boerhaavia coccinea Mill.	L
B. diffusa L.	L
B. paniculata Rich.	L
B. torreyana Standley	L
Bougainvillea spectabilis Willd.	H
Mirabilis jalapa L.	H
Nymphaeaceae	
Nuphar variegatum Engelm.	H
Oleaceae	
Ligustrum vulgare L.	H
Syringa vulgaris L.	H
Onagraceae	
Oenothera biennis L.	H
Oxalidaceae	
Oxalis stricta L.	H
Papaveraceae	
Macleaya cordata (Willd.) R. Br.	H
Parkeriaceae	
Ceratopteris thalictroides Brongn.	H
Passifloraceae	
Passiflora caerulea L.	H
Pinaceae	
Juniperus communis L.	H
Larix laricina (Du Roi) K. Koch	H
Picea glauca (Moench) Voss	H
Pinus nigra Arnold	H
Thuja occidentalis L.	H
Plantaginaceae	
Plantago lanceolata L.	H
P. rugelii Dcne.	H

TABLE II.—*Continued*

Species[1]	r[2]
Polemoniaceae	
Cobaea scandens Cav.	H
Collomia biflora Brand	H
Gilia abrotanifolia Nutt.	H
G. achilleaefolia Benth.	H
G. capitata Sims	H
G. grandiflora A. Gray	H
G. micrantha Steud.	H
G. multicaulis Benth.	H
G. rubra (L.) Heller	H
G. tricolor Benth.	H
Phlox drummondii Hook.	H
Polemonium flavum Greene	H
P. pauciflorum Wats.	H
P. richardsonii R. Grah.	H
Polygonaceae	
Polygonum aviculare L.	H
P. convolvulus L.	H
P. erectum L.	H
P. pensylvanicum L.	H
P. persicaria L.	H
P. reynoutria Makino	H
Rheum rhaponticum L.	H
Rumex acetosella L.	H
Rumex crispus L.	H
Portulacaceae	
Portulaca grandiflora Hook.	L
P. oleracea L.	L
Primulaceae	
Anagallis linifolia L.	H
Primula alpicola Stapf	H
P. denticulata Sm.	H
P. florindae F. K. Ward	H
Punicaceae	
Punica granatum L.	H
Ranunculaceae	
Clematis verticillaris DC.	H
Delphinium ajacis L.	H
Paeonia lactiflora Pall.	H
Resedaceae	
Reseda odorata L.	H
Rhamnaceae	
Rhamnus cathartica L.	H

TABLE II.—*Continued*

Species[1]	r[2]
Rosaceae	
Fragaria vesca L.	H
Malus ioensis Britton	H
Physocarpus opulifolius (L.) Maxim.	H
Potentilla fruticosa L.	H
P. norvegica L.	H
P. simplex Michx.	H
Prunus persica (L.) Batsch	H
P. triloba Lindl.	H
Rosa pimpinellifolia L.	H
Rubus idaeus L.	H
Sorbus americana Marsh.	H
Spiraea alba Du Roi	H
Rutaceae	
Citrus limon Burm.	H
Fortunella japonica Swingle	H
Ruta graveolens L.	H
Zanthoxylum americanum Mill.	H
Salicaceae	
Populus alba L.	H
Salix amygdaloides Anderss.	H
Salix interior Rowlee	H
Sapindaceae	
Cardiospermum halicacabum L.	H
Saururaceae	
Saururus cernuus L.	H
Saxifragaceae	
Heuchera sanguinea Engelm.	H
Ribes alpinum L.	H
Scrophulariaceae	
Antirrhinum majus L.	H
Linaria vulgaris Mill.	H
Pentstemon barbatus Roth	H
Simaroubaceae	
Ailanthus altissima (Mill.) Swingle	H
Solanaceae	
Datura stramonium L.	H
Lycopersicon esculentum Mill.	H
Nicotiana glauca Graham	H
N. tabacum L.	H
Petunia hybrida Hort.	H
Physalis heterophylla Nees	H

TABLE II.—*Continued*

Species[1]	Γ[2]
Solanum dulcamara L.	H
S. melongena L.	H
S. nigrum L.	H
S. tuberosum L.	H
Taxaceae	
Taxus canadensis Marsh.	H
T. cuspidata Sieb. & Zucc.	H
Taxodioideae	
Taxodium distichum Rich.	H
Tiliaceae	
Tilia americana L.	H
Tropaeolaceae	
Tropaeolum majus L.	H
Ulmaceae	
Celtis occidentalis L.	H
Ulmus americana L.	H
Ulmus pumila L.	H
Umbelliferae	
Daucus carota L.	H
Pastinaca sativa L.	H
Urticaceae	
Parietaria pensylvanica Muhl.	H
Pilea microphylla Liebm.	H
Verbenaceae	
Verbena bracteata Lag. & Rodr.	H
V. stricta Vent.	H
Violaceae	
Viola tricolor L.	H
Vitaceae	
Parthenocissus tricuspidata (Sieb. & Zucc.) Planch.	H
Vitis argentifolia (Munson) Fern.	H
V. riparia Michx.	H
Zygophyllaceae	
Kallstroemia maxima L.	L
K. pubescens (G. Don) Dandy	L
K. rosei Rydb.	L
Tribulus cistoides L.	L
T. hystrix R. Br.	L
T. terrestris L.	L
Zygophyllum aurantiacum F. Muell.	H
Z. coccineum L.	H
Z. dumosum Boiss.	H
Z. fabago L.	H
Z. howittii F. Muell.	H
Z. iodocarpum F. Muell.	H
Z. simplex L.	L

[1] Dicotyledon species were supplied by many sources, both locally and abroad. Bailey (1), Fernald (9), Index Kewensis, and Gray Herbarium Card Index were used as sources of authority when authorities were not supplied to us with the species name.

[2] Species classified as low (L) had Γ of 10 μl/l CO_2 or less, and those classified as high (H) had Γ of 40 μl/l CO_2 or greater.

[3] Compensation point actually less than 40 μl/l CO_2; see text.

as a group, when measured in a given environment. As mentioned previously, high Γ are affected by temperature and are strongly dependent on O_2 concentration (10, 11, 19). The Γ of C_3 species were near 45 μl/l CO_2 at 23 C and near 60 μl/l at 30 C. It is unlikely, however, that either temperature or O_2 concentration were greatly different in our experiments and those mentioned above.

Two species in our experiments did respond differently from all others that we measured. One of these, *Moricandia arvensis* (L.) DC., a crucifer, had a Γ of 25 μl/l under conditions where barley had a Γ of 45 μl/l and maize had a Γ of 0 μl/l. The Γ of *M. arvensis* was checked numerous times on leaves from many different plants grown in several environments and its Γ was always intermediate between that of high and low groups. The values obtained in various conditions ranged from 23 to 29 μl/l. In one experiment, *M. arvensis* and seven other Crucifereae—*Brassica napobrassica* Mill., *B. oleracea* L., B. *rapa* L., *B. septiceps* Bailey, *Crambe maritima* L., *Raphanus sativas* L., and *Farsetia clypeata* R. Br.—were grown at the same time. The seven species had Γ greater than 40 μl/l, while *M. arvensis* had a Γ of 26 μl/l. In further experiments, Moricandia's pathway of carbon fixation, photosynthetic response to light, leaf anatomy, and metabolism of glycolate were investigated (3). In all cases, the response was typical of C_3 plants; therefore, *M. arvensis* is classified as a high Γ species in Table II, although its Γ was actually less than 40 μl/l.

The second species which responded differently from all others was *Panicum milioides* Nees ex Trin. In an earlier publication (22), this species was classified as having a high Γ. It was drawn to our attention by Dr. Tom Neales (personal communication) that he had found *P. milioides* to have the enzyme composition of a C_4 plant. As a result, this species has been checked repeatedly, and a range of Γ between 12 and 50 μl/l has been obtained. Most often the Γ has been between 12 and 20 μl/l. In other respects, including leaf anatomy (7) and enzymic composition as mentioned above, *P. milioides* appears to be typical of C_4 species and therefore has been classified as low Γ in Table I.

Dr. J. Raynal of the Museum of Natural History in Paris pointed out that our report on *Cyperus papyrus* L. as having a high Γ (22) did not agree with other characteristics of the species such as leaf anatomy (personal communication). We rechecked our material and found that the species which we identified as *C. papyrus* in the earlier publication was actually *C. alternifolius* L. *Cyperus papyrus* has a low Γ as shown in Table I.

Table III. *List of Families and Number of Species for Which CO_2 Compensation Points Have Been Reported in Addition to Those Listed in Tables I and II*

Family	Total species	High Γ	Low Γ	References
	Monocotyledons			
Cyperaceae	28	9	19	2,8,16,25[1]
Gramineae	43	20	23	2,6,8,16
Musaceae	1	1		16
Palmae	1	1		16
Pontederiaceae	1	1		2
	Dicotyledons			
Aceraceae	3	3		5
Amaranthaceae	19	5	14	16,24
Chenopodiaceae	20	11	9	2,8,23,24,25
Commelinaceae	1	1		2
Compositae	3	3		2[1]
Convolvulaceae	1	1		2[1]
Corylaceae	2	2		5
Cruciferae	1	1		2
Euphorbiaceae	7	5	2	16
Fagaceae	9	9		5
Hippocastanaceae	1	1		5
Juglandaceae	1	1		5
Leguminosae	12	12		2,5,8[1]
Magnoliaceae	2	2		5
Malvaceae	3	3		2[1]
Nyctaginaceae	1	1		16
Oleaceae	3	3		5
Phytolaecaceae	1	1		5
Pinaceae	10	10		5
Platanaceae	1	1		5
Portulacaceae	4	1	3	16,24
Rosaceae	1	1		5
Rubiaceae	1	1		2
Salicaceae	1	1		5

[1] Chen *et al.* (2) reported intermediate values for some species in this family.

In several genera, there are both high and low Γ species. Among monocotyledons, these occur in *Panicum* (Gramineae) and in *Cyperus* (Cyperaceae). Among dicotyledons, both types are found in *Atriplex* (Chenopodiaceae), *Bassia* (Chenopodiaceae), *Euphorbia* (Euphorbiaceae), and *Zygophyllum* (Zygophyllaceae). The Cyperus, Panicum, and Euphorbia are very large genera and are composed of several subgenera. Classification into taxa has been difficult in these genera, and the different Γ types are found in different subgenera. It may be that the different types represent major evolutionary shifts which should be classified as separate genera. In fact, it is possible that measuring Γ might be a useful tool in organizing the taxa of these complex genera.

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