Impact Factors and Citation Rates in *Plant Physiology*

Ever since the Institute for Scientific Information (ISI) developed the large database from which it could extract information about the frequency at which published articles were being cited, ISI's "impact factor" has been widely used by young scientists to try to target their research articles to specific journals and by administrators to evaluate the scientific achievements of scientists. This development has had both positive and negative consequences.

The impact factor of *Plant Physiology* has gradually risen over the past few years from around 3.0 to 4.5. What does this mean? Is *Plant Physiology* now a "better" journal? I consider it but one indication of the effect that our Journal has had and continues to have in the field of plant biology. Whereas impact factors are widely quoted and used, few people know how they are calculated or understand what they mean. The ISI impact factor of a journal is "the number of current citations to articles published in a specific journal in a 2-year period divided by the total number of articles published in the same journal in the corresponding 2-year period." Sound complicated? It is. The impact factor states nothing about the value of the science in a particular article, about the number of times that article has been cited, or about citations in the next 2 or 10 years. Several years ago, I calculated impact factors for individual research articles in *Plant Physiology*. I found a 25-fold range: Some had impact factors of 25, others of 1! Although ISI states at its Web site: "Perhaps the most important and recent use of impact is in the process of academic evaluation" (http://www.isinet.com/help/glossary.html), I can think of no better reason why administrators should not use the impact factor of a journal to judge the impact of a scientific contribution than the range of values found for individual articles.

ISI recently introduced a new number, best described as the $t_{1/2}$ of citations, which addresses the longevity of citations. It is in this department that *Plant Physiology* really shines! Our $t_{1/2}$ is a remarkable 7 years, meaning that the citation rate drops off slowly and that articles published in *Plant Physiology* continue to be cited for many years. Surprisingly, some articles published during our first year of publication (1926) are still being cited! Journals or articles with a larger $t_{1/2}$ also have a higher total citation rate, which can be defined as the total citations over the lifetime of the journal or article. Of the major plant biology journals, we have the highest citation rate, according to the Highwire Press Web site (http://www.highwire.stanford.edu). This is in part because we are an old journal (75 years), in part because we publish around 400 articles per year, and in part because many of those articles continue to be cited for many years.

When the high citation rate of *Plant Physiology* came to my attention last year, I asked Jennifer Reiswig, a University of California—San Diego library information analyst, to do some research on *Plant Physiology's* 20 most frequently cited papers published since 1980. This ISI database search produced interesting results. Because citations are cumulative, the 20 most frequently cited papers published since 1980 were nearly all published before 1990. The only exception is "Genes Galore" by Tom Newman et al., published in 1996. Among the top 20 most frequently cited research papers published in *Plant Physiology* were contributions to photosynthesis, ecophysiology, photobiology, plant–pathogen interactions, biochemistry, stress physiology, and methodology. Papers in this category were cited 200 to 450 times in that 20-year period (1980–1999). Top honors with 451 citations go to John Mullet et al. for an article on the proteins associated with photosystem I, published in 1980, and to Mauch et al. (1988; 449 citations) for an article on the synergistic effect of chitinase and glucanase on the inhibition of fungal growth. (There may be articles with more citations that were published in earlier years.) It is important to note that citations in publications (journals or books) not tabulated by ISI are not counted in this total.

Jennifer Reiswig also tabulated the two research papers published each year that were the most frequently cited in subsequent years. This produced a different list (Table I), because recently published papers (1990 and later) have not had the opportunity to be cited as frequently as older papers and, therefore, did not appear on our first list of the 20 most cited papers. The subject matter of this second list was even more diverse and showed the emergence of new subjects including cell biology, development, and molecular biology. The citation rate was time dependent, and indicated that high impact papers are cited 200 to 300 times over their lifetime. The positions of the papers on this list for the most recent years (1995–1998) may still change if the analysis is repeated 5 or 10 years hence. Papers that are "hot" now may not stand the test of time!

Among these papers in Table I, one can readily discern quite a few that are "founder papers." I define *founder papers* here as studies that were part of a handful of papers that initiated a new subfield of research in plant biology. The papers were frequently cited as this subfield quickly expanded because the field drew the attention of new researchers. Whether the peer reviewers of these seminal papers realized the significance of the studies at the time they re-

Table I. *The two most frequently cited research papers published in Plant Physiology from each year: 1980–1998*

Citations[a]	First Author	Volume	Page	Year	Subject[b]
21	Fryer, MJ	116	571	1998	Guard cell protein kinase
21	Li, JX	116	785	1998	Photosynthesis under stress
42	Nomura, T	113	31	1997	Brassinosteroids
40	Weig, A	114	1,347	1997	Aquaporin gene family
69	Xu, DP	110	249	1996	LEA proteins in stress tolerance
57	May, MJ	110	1,367	1996	Reactive oxygen species in defense
98	Kishore, PBK	108	1,387	1995	Proline and osmotolerance
82	Phillips, AL	108	1,049	1995	GA20-oxidase cloning
168	Reed, JW	104	1,139	1994	Functions of PhyA and PhyB
115	Wan, YC	104	37	1994	Barley transformation
177	Nagatani, A	102	269	1993	PhyA mutants
136	Weeks, JT	102	1,077	1993	Wheat transformation
126	Farmer, EE	98	995	1992	Gene regulation by jasmonate
105	Höfte, H	99	561	1992	Aquaporins
217	Thomas, RB	96	627	1991	Root restriction and photosynthesis
155	Rasmussen, JB	97	1,342	1991	Systemic induction of salicylate
138	Samac, DA	93	907	1990	Genes encoding chitinases
125	Poorter, H	94	621	1990	Carbon and nitrogen economy of wild species
300	Apostol, I	90	109	1989	Oxidative burst during elicitation
297	Sage, RF	89	590	1989	Acclimation of photosynthesis to elevated CO_2
449	Mauch, F	88	936	1988	Antifungal hydrolases
177	Mauch, F	87	325	1988	Antifungal hydrolases
292	Demmig, B	84	218	1987	Role of the xantophyll cycle
171	Walker-Simmons, B	84	61	1987	Abscisic acid and sprouting
203	Norby, RJ	82	83	1986	CO_2 enrichment and growth of oak seedlings
166	Romheld, V	80	175	1986	Uptake of iron phytosiderophores
306	Inskeep, WP	77	483	1985	Extinction coefficients of Chla and Chlb
192	Finkelstein, RR	78	630	1985	Abscisic acid and seed maturation
289	Ray, TB	75	827	1984	Chlorsulfuron site of action
261	Shaner, DL	76	545	1984	Imidozalines and AHA synthase
255	Evans, JR	72	297	1983	Nitrogen and photosynthesis in flag leaf
238	Nothnagel, EA	71	916	1983	GalUA oligosaccharides as elicitors
319	Flores, HE	69	701	1982	High-performance liquid chromatography of polyamines
306	Gallagher, SR	70	1,335	1982	Characterization of plasma membrane $[H^+]$ATPase
192	Hahn, MG	68	1,161	1981	Cell wall elicitors of phytoalexins
181	Graham, JH	68	548	1981	Mechanism of P-inhibition of mycorrhiza
451	Mullet, JE	65	814	1980	Chlorophyll proteins of photosystem I
297	Badger, MR	66	407	1980	CO_2 concentrating mechanism in *Chlamydomonas*

[a] No. of citations since date of publication; analysis was performed with ISI database in December 1999; for the later years (1995–1998), papers not on the list could displace the two papers now at the top if the analysis is repeated several years from now. [b] Only research papers have been included. Reviews were eliminated from the list.

viewed them for *Plant Physiology*, we do not know. Unfortunately, our records are not good enough to try to research this interesting question. Perhaps we should ask the authors!

Examples of *founder papers* on this list might be Apostol et al. (1989): Rapid elicitation of an oxidative burst during elicitation of cultured plant cells: role in defense and signal transduction (300 citations). Apostol's was not the first article on this topic, but research on the oxidative burst intensified in subsequent years. Another example is Mauch et al. (1988; 449 citations), who reported that fungal growth could be inhibited by combining chitinase with β-glucanase in the growth medium. This seminal observation led to other research on the use of the genes encoding these enzymes in genetic engineering for fungal resistance. Nagatani et al. (1993; 177 citations) reported the characterization of the first Arabidopsis mutants deficient in phytochrome A, and the next year Reed et al. (1994; 168 citations) reported that phytochrome A and phytochrome B have overlapping but distinct functions. This field has also taken off in recent years. These are but a few examples of high impact papers that were published in *Plant Physiology*, a medium impact journal.

What can be deduced from this exercise in information retrieval?

1. After 75 years, *Plant Physiology* remains an excellent vehicle for the publication of high qual-

ity articles in plant biology. Our data show that articles we can now recognize as having been important for the discipline were highly cited and continue to be highly cited for many years after their publication.

2. In deciding where to publish an article, authors should target the readership of a journal, not its impact factor. "By whom would I like this article to be read?" should be the guiding question. If you think the impact factor of the journal isimportant, look at the staying power of the ci-ations as well.
3. In trying to evaluate the impact of scientific contributions, science administrators should not rely on the ISI impact factor of a journal, because there are large differences in the calculated ISI impact factors of individual articles in a journal. There is really no short-cut to the difficult job of evaluating the substance of scientific contributions.

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