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Mapping soybean physiology research based on the web of science

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Abstract

The aim of this paper was to map the scientific research on soybean physiology by using bibliographic review and analyses of papers indexed up to July 31, 2014 in the web of science database. A total of 1682 non-redundant bibliographic records were curated. The soybean physiology research experienced two major periods. The first period was from 1943 when the first soybean paper was published to 1989 during which a small and gradual increase took place with no more than 12 annual publications. The second period being from 1990 to present, saw a substantial increase in annual publications ranging from 35 to 92 per year. Authors representing a total of 76 countries were involved in soybean physiology research. Drs. T.R. Sinclair and Dr. D.B. Egli were the most productive authors while the USDA/ARS, University of Illinois and Iowa State University published the most influential articles. The most productive journals were the Journals of Crop Science, Plant Physiology, Plant and Soil, Field Crops Research the most research subject categories were nitrogen fixation, photosynthesis, growth, mineral nutrition, genotypes, drought stress, yield and quality. Gene expression for quality and yield under drought stress has become a favored topic for soybean physiology. Eight out of the top ten productive institutions were located in the USA. The USA exceeded all other countries with the most independent and collaborative papers on soybean physiology research. The status of publications on soybean physiology described here may serve as a tool for guiding researchers in their future work.

Keywords: Soybean physiology; Bibliometrics analysis; History; Geographic distribution; Popular issues.

Introduction

Soybean, *Glycine max* (L.) Merr., the leading oilseed crop produced and consumed in the world today, remains the world's primary source of protein feed supplement for livestock and vegetable oil for human consumption. Soybean accounts for 59% of all oilseeds and is the world's major vegetable oil (FAO, 2013a). A remarkable crop, soybean has been used for over 5000 years by humans (Wang, 1991). It is an integral part of modern agriculture and the food system in major producing countries and also has a major social and economic influence on international trade.

About 50 countries around the world grow soybean and the total soybean production was estimated at 269 million Mg in 2012/2013. Among the 20 highest producing

countries, the USA is currently the largest producer of soybean, followed by Brazil, Argentina, the People's Republic of China and India. Italy is the largest soybean producer in the European Union. The Russian Federation and Ukraine produce most of the soybean in Eastern Europe, while South Africa and Nigeria are the main producers in Africa (FAO, 2013b). Current world production of soybean far exceeds that of any other edible oilseeds. Seed yields of soybean have increased about 1% per year in major soybean-producing countries. There is no indication that this rate is going to slow down in near the future.

The coupling of basic and applied sciences in soybean improvement, production and usage contributed much to soybean's worldwide significance. The emergent genetic and agronomic technologies in the last century had a significant impact on the soybean industry. Some newly evolved production practices offer great promises. For example, the early soybean production system (ESPS) developed in the mid-southern USA. This system replaces the conventional soybean production system (CSPS) which includes May and June planting of later-maturing cultivars (Boquet, 1998; Heatherly and Bowers, 1998). There are now better genetic and agronomic approaches to dealing with some old as well as new yield limiting diseases and pests. Soybean physiology research has been instrumental in revolutionizing approaches to improving soybean yield, pest protection and seed quality, to understanding factors affecting yield and production costs and to accelerating worldwide soybean production (Harper, 1987; Sinclair and Shiraiwa, 1993; Purcell et al., 2000; Egli and Bruening, 2001; Liu et al., 2008; Sinclair and Vadez, 2012; Van Roekel and Purcell, 2014). Therefore, a systematic analysis of the origin and evolution of soybean physiology seems to be necessary at this time for understanding the development and current state of this discipline, for identifying and saluting those pioneer researchers who have made significant contributions in converting this plant from a forage crop to a grain crop and more importantly for improving the future research. Boulaine (1989) states that a good method to illustrate the historical evolution of a soil science discipline, is to analyze the history of the people involved. Through this historical analysis approach, their ideas, concepts, methods and techniques become apparent. Publication numbers can also give important clues about emerging disciplines.

In this research, we employed a bibliometric analysis of published studies on soybean physiology from 1943 to July, 2014 in the hope of providing a better understanding of research on soybean physiology around the world. The current paper was not meant to be an update on the research advances taking place in soybean physiology after the first publication written 7 decades ago in 1943, but identifies and highlights major macro-changes that have occurred in soybean physiology research from the web of science perspective. Such a retrospective look at the science of crop physiology has not been well recognized (Evans, 1996; Specht et al., 1999). New data, findings as well as prior changes in soybean physiology will be of significance to the physiological community for seeking evidence of the increasing or waning interest in different subject areas (Gan et al., 2002; Lawn and James, 2011; Zhang et al., 2014). Thus, this paper will serve as a foundation providing useful information to researchers and graduate students interested in knowing the general trend, history, main subject categories, major journals, author productivity, geographic distribution of publications and current and important topics of soybean physiology research.

Data and methodology

We built our bibliometric database of "soybean physiology" using web of knowledge [v.5.13] - web of science (http://pcs.webofknowledge.com/ SessionError.cgi? DestApp= WOS&CSID=S1CALRTQ1EdItqzkgdl&Error=Server.sessionNotFound) database, with the main subject=[(soybean or *Glycine max*) and physiology], on literatures in SCI-EXPANDED from 1900-2014 (as of July 31, 2014).

A total of 2698 papers were obtained in the SCI databases. After an intensive manual reading and evaluation, a total of 1682 out of 2698 publications were found to be soybean physiology related, representing a nearly 62.3% of the indexed papers selected from the database. These 1682 articles were all peer-reviewed original research papers. The data were first analyzed by the software of Thomson Data Analyzer (TDA) (Thomson Reuters) and they were further bibliometrically analyzed to obtain required indicators including publication number, journals of main publication and sources of reference, research institution, affiliation of authors and main research subjects, number of publications and total citation from the top productive authors. Collaboration type was determined by the addresses of the authors, where the term "single country" was assigned if the authors' addresses were from the same country; and "international collaboration" was designated to those articles that were by authors from multiple countries (Zhang et al., 2010). In determining collaborative works among authors, institutions, or countries, each signatory on publications was treated equally. The impact factors (IF) were taken from the Journal Citation Report (JCR) published in 2013, which had the latest data available. The IF was used to evaluate a journal's relative importance, especially when compared with other journals in the same field. Because keywords were not available by the web of science in its database during the period of 1943-1989, we simply used the titles to identify the research focuses for this period, while keywords were available and used to identify the subject categories for all the publications from 1990 to July, 2014. Microsoft Excel was used for basic statistic analysis and preparation of tables and graphs that are sufficient to illustrate the various trends.

Results and Discussion

The first paper on soybean physiology research

The first paper titled "Inheritance and physiology of efficiency in iron utilization in soybeans" was published in Genetics 28: 253-268, May, 1943 by Dr. Martin G. Weiss from the Iowa State College (currently known as Iowa State University). This paper was part of the author's Ph.D. dissertation. The research highlighted the differences in chlorosis typical of iron deficiency noted in 1938 among a considerable number of soybean varieties when tested on calcareous soils after the first introduction into the United States from Manchuria (Northeast China). Because these strains were not greatly different morphologically, it was thought that such wide differences in chlorosis would especially lend themselves to a study of the inheritance and physiology of iron availability in plants.

Weiss (1943) proposed that differences in efficiency of iron utilization were conditioned by a single gene. The gene conditioning a greater efficiency in iron utilization seemed to be expressed by its action in producing a higher hydrogen ion concentration, soluble iron, potassium and lower total iron content of aerial tissues than its allele which showed conditions of inefficiency in iron utilization in its homozygous state. Results and the message from in his work are still to be regarded as valuable today as first published in 1943. A recent paper entitled "Morpho-physiological parameters affecting iron deficiency chlorosis in soybean (*Glycine max* L.)" (Vasconcelos and Grusak, 2014) was an evidence.

A description on the history of soybean physiology research by titles (1950-1989)

In the early four decades (1950-1989), the publication rate in soybean physiology remained very low as compared to the later decades (Figure 1). There were a total of 106 publications during the early period which accounted for only 6.3% of the total 1682 publications in soybean physiology (as of July 2014). Despite the low rate, the number of publications per decade exhibited a gradual increase with being one in the 1950s, eight in the 1960s, thirty in 1970s and sixty seven in 1980s, respectively. This trend indicated the interest in soybean physiology research was on the rising.

The 1950s' paper was entitled "Physiological factors affecting composition of soybeans" by Howell and Cartter (1953). The authors focused on the correlation of temperatures with oil percentage in mature beans during certain portions of the pod filling stage. Researchers in 1960s investigated preliminarily on the plant nutrition and management (Cooper and Girton, 1963; Sadasiva, 1965), physiological changes associated with infection by and resistance to downy mildew fungus *Peronospora manschurica* (Millikan and Wyllie, 1966), aspects of nodulation by rhizobia including host physiology and cobamide coenzyme contents (Kliewer and Evans, 1963; Hubbell and Elkan, 1967). The physiological tests on the activity of actinomycetes from rhizosphere + non-rhizosphere soils were also investigated (Abraham and Herr, 1964).

Among the 30 articles published in 1970s, 7 papers focused on water stress effects on soybean growth, development, evaporation, photosynthesis, soil-water depletion, nitrogen fixation, root distribution, leaf water potential, transpiration and yield (Sprent, 1971; Read and Bartlett, 1972; Rawson et al., 1978; Turner et al., 1978; Burch et al., 1978; Constable and Hearn, 1978). The physiological approach to soybean breeding was initiated, based on heritability and response to selection of physiological traits related to yield in 1970s (Buzzell and Butery, 1977). The physiological aspect of O_3 susceptibility in soybean cultivars (Chimikis and Tingey, 1976) and role of leg-hemoglobin in soybean root nodules (Bergerse et al., 1973) were also initiated during this period. These authors were pioneers responsible for leading the respective research directions. Four papers evaluated the physiological aspects of soybean in response to herbicides including Metribuzin, 2, 4-D and Atrazine (Rudolph and Terrill, 1975; Davidonis et al., 1977; Fedtke, 1979). There were two papers focusing on thermo-period (Warrington et al., 1976; Warrington et al., 1977) and two other papers on physiological maturity (Crookston and Hill, 1978; Tekrony et al., 1979). The rest of the 1970s' publication focused on senescing tap root-nodules (Klucas and Arp, 1977), seed

deterioration (Srivastava and Gill, 1975), responses of cultivars to planting arrangements (Lawn et al., 1977), effectiveness of rooting system as nutrient absorption surface (Raper and Barber, 1970), ultrastructural and physiological differences in genetically altered levels of photosynthetic pigments (Crang and Noble, 1974) and early site damage to seedlings following ozonation (Frick and Cherry, 1974).

Among the 67 publications of 1980s, main subject categories were shifted to climate change, nitrogen fixation, photosynthesis, water stress, phytohormones, respiration, seed quality, mineral nutrition and roots (Mislevy et al., 1989). Climate change became a popular topic with 12 publications, which primarily focused on yield and physiological responses to simulated acid rain and gaseous pollutants (Norby and Luxmoore, 1983; Norby et al., 1986), ambient ozone effect and fumigation (Smith and Brennan, 1984; Takemoto et al., 1987), CO_2-enrichment (Havelka et al., 1984; Ackerson et al., 1984), supplemental UV-B radiation (Murali and Teramura, 1986) and elevated night temperature (Seddigh and Jolliff, 1984). Thus, 1980s could be viewed as the beginning of the shifting interest in the effects of climate change on soybeans from the crop physiology perspective.

Nitrogen fixation, greatly differed from 1970s, became another important research topic in 1980s with 9 publications. The researchers mainly examined (1) the physiological characteristics of indigenous *Rhizobium- japonicum* and their effects on growth and development (Kao and Lin, 1983; Keyser et al., 1982); (2) structural and physiological bases for effectivity of soybean nodules formed by fast-growing/slow-growing bacteria as well as nodule physiology of the super-noduating soybean (Day et al., 1987; Walsh et al., 1988); (3) proteolytic activity in root nodules, host cell cytosol and bacteroids during physiological development and senescence (Pfeiffer et al., 1983); (4) elevated CO_2 effects on reproductive physiology, N_2 fixation and examination on the physiology and formation of nodules by the techniques of isolating root culture through double feeding (Racca, 1980; Zampini et al., 1984).

Photosynthesis research in 1980s mainly examined transport kinetics of C11 labeled photosynthates (Fritz et al., 1986), diurnal time course of leaf photosynthesis using a physiologically based steady-state model (Tenhunen et al., 1980), the variation in specific leaf weight and protein-components (Wells et al., 1986a), vertical (CO_2)-C-14 labeling and dry weight partitioning of cultivars differing in canopy photosynthesis (Wells et al., 1986b). Soybean chlorophyll mutant at two ploidy levels (Hatfield and Palmer, 1983) and relationship between photosynthetic rate and transpiration rate per vapor-pressure deficit by remote-monitoring (Inoue, 1987) were studied. The physiological responses and morphogenic changes of various genotypes to water stress in different soils and restricted root zone volume were investigated (Dasilva and Resck, 1981; Vignes et al., 1986; Griffin et al., 1989; Carmi et al., 1985).

The effect of ethylene in the soil atmosphere on soybean seedling and root growth (Nakayama and Ota, 1980a; Nakayama and Ota, 1980b), physiological site of ethylene effects on CO_2 assimilation (Taylor and Gunderson, 1988) and the physiological basis for cytokinin induced increase in pod set (Carlson et al., 1987) were also studied.

A series of publications relating to respiration were published, including respiration in relation to physiological conditions: N supply and plant age on the behavior of

respiration in the dark period (Yamagishi et al., 1988); effects of preceding light conditions on the time course change of respiration in the following dark period (Yamagishi et al., 1989a), characteristics of respiration in leaves and roots under attached and detached conditions (Yamagishi et al., 1989b); time course changes in leaf N metabolism (Yamagishi et al., 1989c). Seed quality research was primarily focused on the relation to harvesting at physiological maturity; seed physiological quality and field performance (Filho, 1981; Singh and Gupta, 1982; Derezende et al., 1985); the role of physiological factors and fungal pathogens on seed deterioration (Ndmande et al., 1981).

Identification of some polyphenolic compounds was investigated from root exudates (Darcylameta, A., 1986) and the idea of physiological stress on roots-a barrier to maximum soybean yield was proposed (Brown and Haq, 1983). For mineral nutrition, researchers examined manganese critical levels for soybean growth and physiological processes (Ohki, 1981), as well as the influence of P nutrition on P and N utilization efficiencies and associated physiological responses (Fakir et al., 1986; Isreal and Rufty, 1988).

Papers dealt with the influence of antioxidant treatment and herbicides on yield, nodulation and physiological quality of seeds (Smith and Brennan, 1986); higher yield in new, early-maturing soybean cultivars (Mcblain and Hume, 1980); the physiological and genetic analysis of pod shattering (Tsuchiya, 1987), effects of allelopathic chemicals and NO_2 on soybean growth and biochemical and physiological responses of soybean (Patterson, 1981; Sabaratnam and Gupta, 1988) were published during this period. Besides, whole-plant indicator and a visual indicator of physiological maturity in soybean plants were also investigated (Gbikpi and Crookston, 1981; Tekrony et al., 1981).

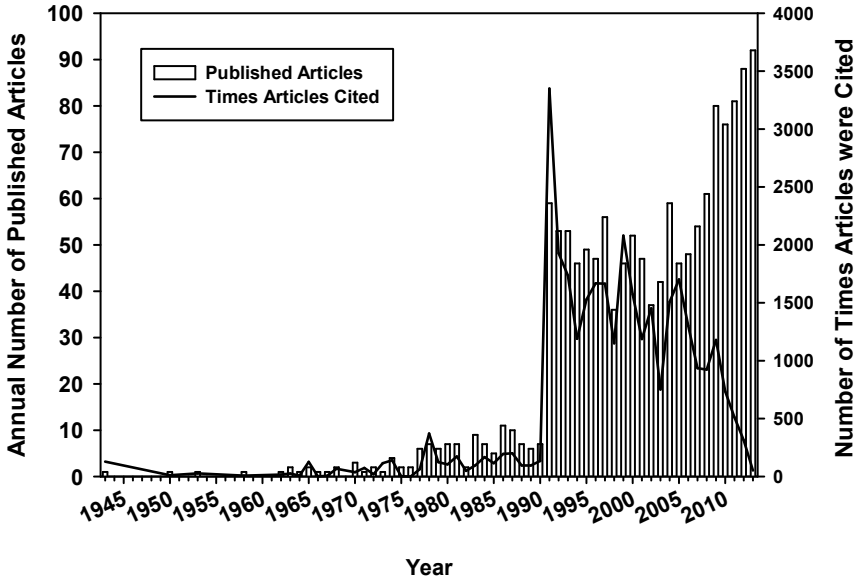

Figure 1. Number of publications using the word soybean or *Glycine max* and physiology in the title or in the author keywords from1943- July, 2014.

A glimpse on the main subjects of soybean physiology research by keywords (1990-July 31, 2014)

As indicated in Figure 1, research publications in soybean physiology experienced a period of rather slow growth from 1943 to 1989 and a period of rapid expansion and remarkable growth from 1990 to present (as of July 2014). A total of 1572 papers were published since 1990, with 602 publications in 1990s, 578 publications during the period of 2000-2009 and 395 publications from 2010 to the end of July, 2014 (Figure 1), representing 93.6% of the total publication pool (out of 1682) with an average of 65 papers per year, which was a 10-fold increase in the number of publications compared to the early four decades.

Twenty-nine (29) main subject keywords were used to categorize the publications for the period from 1990-July, 2014 (Table 1). The most common categories during 1990-1999 were nitrogen fixation, photosynthesis, growth, development, gene expression, genotypes, lipoxygenase, hormones, senescence, respiration, resistance, carbon partitioning, plasma membrane and storage protein (Calvino et al., 2003; Liu et al., 2010; Jin et al., 2011). The study on water stress, elevated CO_2, rhizosphere, acclimation, competition and ozone were mostly associated with environmental and ecological factors (Koti et al., 2007; Liu et al., 2013; Zhang et al., 2013; Zhang et al., 2014a; Zhang et al., 2014b). During the period of 2000-2009, research interests on gene expression, seeds and yield were on the rising, while less attention was paid to the development, respiration, competition, plasma membrane, ozone and storage protein. Other main topics studied in 1990s such as nitrogen fixation, photosynthesis, hormones and senescence remained to be the major interests of the researchers during 2000-2009 (Boote et al., 2001; Liu et al., 2010; Sinclair and Vadez, 2012). A growing interest in research on gene expression, rhizosphere, drought stress, genotypes, seeds, yield and quality has been observed from 1991 to July, 2014, especially in the area of gene expression, drought stress, seed quality and yield (Cao et al., 2011; Wang et al., 2003). The number of papers on gene expression has increased dramatically in recent years because of the increased awareness of its importance as a valuable tool in soybean development and improvement. The numbers of publications for gene expression and drought stress, quality and yield were 29, 45, 19 and 21, respectively from 1990-1999, these numbers either greatly increased or maintained relative steady throughout 2000-2009 with the corresponding numbers being 51, 47, 18, 28, respectively. Moreover considering the last 4 years and 7 months (from 2010-July, 2014), only a half way into this new decade, these corresponding numbers have reached 45, 45, 18 and 23, respectively. This has led to our conclusion that a better understanding of gene expression for quality and yield under drought stress will continue to be the favored topic in soybean physiology research in the future.

As the detailed review on the progress of the 29 subjects is beyond the scope of this paper, readers are encouraged to pursue personal reviews on recently published articles in their interested areas. However, it is important to note that significant progress in research on gene expression, identification, molecular characterization, introduction and over expression of functional genes for improving tolerance to abiotic stresses or enhancing yield and quality through transcriptome, proteome profiling and genome-wide association analysis has been made and such efforts are being actively pursued (Yamazaki and Saito, 2002; Maguire et al., 2002; Hausler et al., 2002; Shamimuzzaman and Vodkin, 2013; Liu et al., 2014).

Table 1. Summary of publications for 29 subjects by keywords from 1990-July, 2014.

Category	No. of publication in 1990-1999	No. of publication in 2000-2009	No. of publication in 2010-July, 2014
Nitrogen fixation	63	49	26
Photosynthesis	61	47	35
Growth	54	56	37
Physiological responses	51	52	46
Drought stress	45	47	45
Development	43	21	7
Mineral nutrition	29	26	9
Gene expression	29	51	45
Soybean Genotypes	28	18	20
Yield	21	28	23
Elevated CO_2	21	11	6
Lipoxygenase	19	13	3
Quality	19	18	18
Hormones	19	15	8
Regulation	17	10	6
Seeds	16	29	13
Rhizosphere	16	18	13
Oxidative stress	14	10	7
Senescence	14	10	1
Respiration	12	3	6
Plant cell culture	11	1	2
Resistance	11	12	5
Modeling	10	5	1
Acclimation	9	2	4
Carbon partitioning	9	7	2
Competition	9	2	1
Plasma membrane	9	1	0
Ozone	8	1	2
Storage protein	8	0	1

Productive core authors and citations

For the past 71 years, a total of 4505 authors published a total of 1682 research papers on soybean physiology with an average of three authors per article. Among these authors, only 280 took part in the research during 1943-1990 and this number had increased to 4289 authors during 1991-July, 2014.

Because of a dramatic increase in author number, the productivity of individual authorship was not dominant. Around 71 authors have published more than 5 articles and 14 authors published more than 8 articles. They were the top 10 publishing authors (Figure 2). The top 10 authors published 156 publications which accounted for 9.28% of the total. Evidently, they had the greatest amount of achievement in their research on soybean physiology. Among the top 10 authors, six authors were from the USA, two from Canada, two from Brazil, one each from China, Japan, Australia and Morocco, respectively.

T.R. Sinclair who published individually and jointly, has the most articles (24). He is followed by D.B. Egli with 16 articles, R.J. Lawn with 14 articles, L.C. Purcell with 13 articles, R.D. Vieira with 11 articles, M. Hungeria and D.B. Layzell with 10 articles (Figure 2). Their H index pertaining to the publications by various authors in soybean physiology was 11, 11, 7, 7, 3, 9 and 8 respectively. The highest number cited by the total 1682 publications of soybean physiology research were papers written by T.R. Sinclair (235), W.R. Fehr (227), D.B. Egli (217), R. Serraj (89), R.J. Lawn (88), J.G. Streeter (85), M.M. Brandford (82), F.J. Bergersen (78), J.E. Board (64) and D.M. TeKrony (63) (Figure 3). While top total citation among authors with 8 articles was led by T.R. Sinclair (515), D.B. Egli (418), L.C. Purcell (409), R. Serraj (334), M. Hungria (274) and E.A. Ainsworth (254) (Figure 2). This indicates that some authors did not publish many articles, but received the higher number of citations. Besides, C. Bailly, R.A. Creelman, A.A. Gitelson, A. Gojon, W.J. Horst, C. Lamb, J.E. Mullet, J.J. Rackis, H.H. Rogers and P. Schopfer also published several most cited publications. This suggests that for an individual author, the productivity may be negatively related with his/her academic value. The pursuit for high level of research might be at the cost of quantity.

Two most cited articles in the 1692 publications were (1) Rapid and sensitive method for quantification of mirogram quantities of protein utilizing principle of protein-dye binding published in Anal. Biochemistry, 1976, 72 (1-2): 248-254, by M.M. Bradford, which was cited 79 times and (2) Stage of development descriptions for soybeans, *Glycine Max* (L.) Merril published in Crop Science, 1971, 11 (6): 929-935, by W.R. Fehr, which was cited by 73 times. We found that these two mostly cited papers were totally related to methodology.

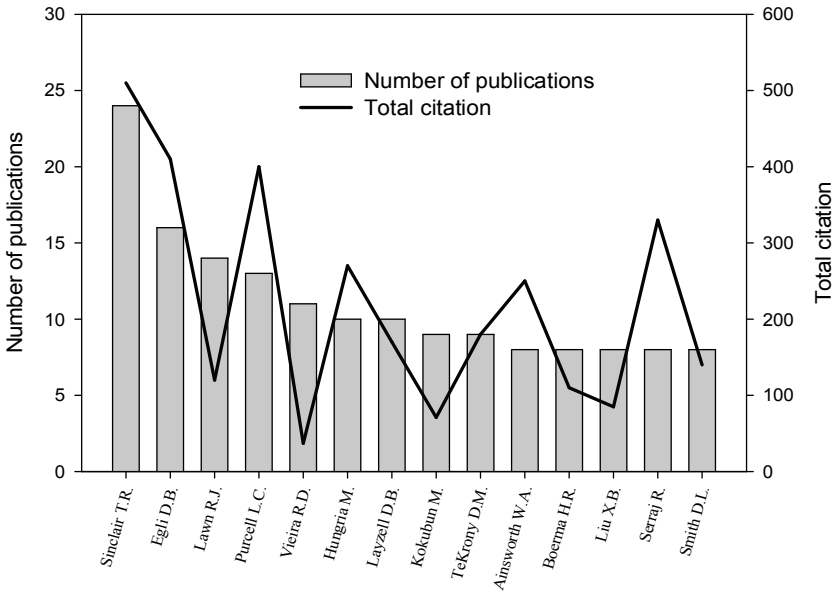

Figure 2. Number of publications and total citation in the top productive authors from 1943 to July, 2014.

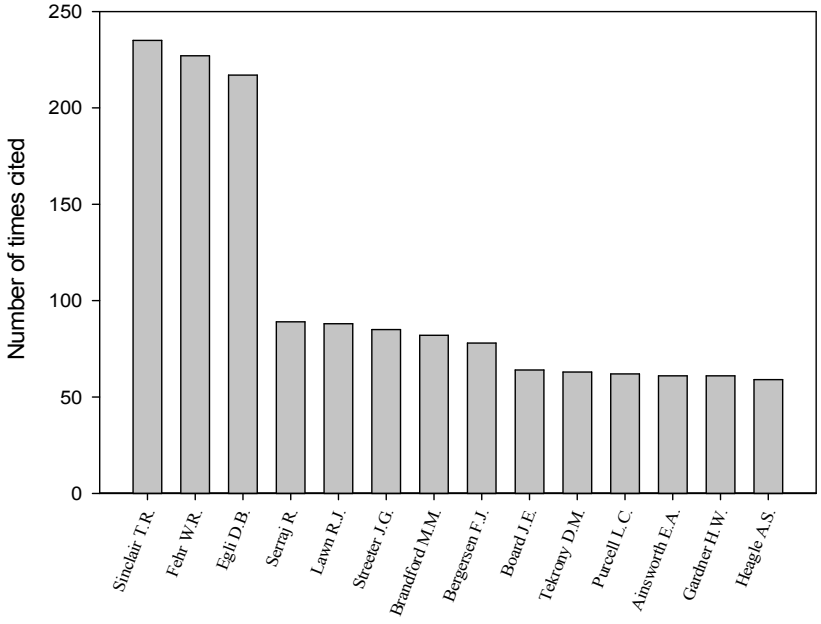

Figure 3. Total number of times cited from publications of core authors by the 1682 publications from 1943 to July, 2014.

Top 10 country affiliation and institutions for the number and citation of the publications

The country affiliation provides information about the country in which the authors worked, within a certain research institution, at the time they were publishing their articles. Web of science database started to list author's country affiliation after 1972, thus the 1682 publications prior to 1972 had no citation for their country affiliation. For the targeted papers published since 1972, publications originated from 76 different countries with 17 country affiliations publishing over 10 papers. The number of country affiliations that studied soybean physiology was 10 during the period of 1972-1990 and increased to 42 during the period of 1991 to 2000, which was four times more than the previous period. From 2001- July, 2014, the number of the country affiliations that studied soybean physiology increased to 72 though affiliations from Brunei, Cuba, Ghana, Georgia, respectively only published one paper during this period. Since the beginning of the 21st century, researchers in over 1/3 of the country affiliations in the world started to pay more research attention to soybean physiology. The number of publications with a single country affiliation was 1031, accounting for 61.3% of the total, while the number of publications with 2-6 country affiliations was 461, accounting for 27.4% of the total. A paper titled "Two defined alleles of the LRR receptor kinase GmNARK in supernodulating soybean govern differing autoregulation of mycorrhization" published in Physiologia Plantarum, 2007, 130 (2): 261-270", had 6 country affiliations. The affiliations were from Austria, Hungary, Germany, Canada, China and Australia. This was the publication with greatest number of country affiliations involved in international collaboration.

The top 10 country affiliation and institutions with more publications and citations are listed in Table 2. Eight out of the 10 top country affiliations except Japan and Canada were from main world soybean-producing countries. The USA ranked No.1 in both the number of publications (529) and citations (14386), which accounted for

27.3% and 43% of the total world publications and citations respectively. The number of publications written by authors from other affiliation countries was Brazil (159), China (109), Japan (104), Australia (58) and Germany (58). Other countries with high numbers were Canada (56), India (51), France (50) and Argentina (42). The USA was the most productive country in international collaboration, with researchers co-authoring papers from 39 countries. The USA also had the highest H index of 35, followed by Germany (10) and France (8). China, the latest country to begin physiological publications had its first paper published in 1997 and has co-authored papers with 13 affiliation countries. After China, the next substantial increase in annual publication was Brazil. However, the paper impact and citations for Chinese authors' were far behind the USA, Germany and France. Among the 10 top affiliation countries, Germany had the highest number of citation for papers (44) and followed by France (41).

A total of 921 institutions conducted research related to soybean physiology. Among them, the USA, Brazil, China, India and Argentina had 319, 124, 113, 61 and 46 institutions respectively. A total 663 institutions from the five soybean-producing countries accounted for 71.9% of the total of all institutions. Only 35 institutions published more than 10 publications related to soybean physiology. Further analysis found that majority of the institutions conducting soybean physiology were universities. There were 521 universities publishing a total of 1054 papers, which accounted for 62.7% of the total publication number.

Eight out of the top 10 institutions with more publications were from the USA with other two institutions coming from Argentina and Brazil (Table 2). The University of Missouri and Iowa State University had the highest H index of 4, followed by the University of Nebraska with H index of 3, North Carolina State University and University of Florida with a H index of 2. On average, less than one paper was published by each Chinese institution in soybean research. There were only 4 institutions publishing more than 10 papers in China, namely the Chinese Academy of Sciences (18), Chinese Agricultural University (14), Nanjing Agricultural University (14) and the Chinese Academy of Agricultural Sciences (11). The Northeast Institute of Geography and Agroecology was the primary contributor to the soybean physiology publication in the Chinese Academy of Sciences system.

Table 2. Top 10 affiliation countries and their impacts from 1943 to July, 2014.

Affiliation Country	Number of publication	Publication number as the first country	Total citation counts	Citation counts of each paper
USA	529	459	14386	27
Brazil	159	151	999	6
China	109	92	1059	10
Japan	104	90	1268	12
Australia	58	41	1390	24
Germany	58	38	2534	44
Canada	56	47	1471	26
India	51	39	347	7
France	50	38	2067	41
Argentina	42	36	867	21

Table 3. Top institutions and their impacts from 1943 to July, 2014.

Institution	Total publication	Total citation counts	Citation counts of each paper
USDA ARS	91	1749	19
Univ Illinois	51	839	16
EMBRAPA	42	365	9
Iowa State Univ	34	896	26
N Carolina State Univ	33	647	20
Univ Minnesota	32	561	18
Univ Fed Vicosa	25	127	5
Univ Florida	25	862	34
Univ Nebraska	25	877	35
Univ Missouri	24	864	36

Annual citation, journals of main publication and sources of reference

The total number of citation from the 1682 papers published during the past 71 years was 33,223 and the number (times) of average citations for each paper was 19.8. A total of 1237 publications were cited more than one time. The peak citation period was from 1991 to 2009. The year of 1991 accounted for the highest number of citations. Publications in this year had cited 3349 times and the maximum citations for a paper was as high as 57. The two papers with the highest citations were also published in 1991. These papers were "Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration- a model that includes a laminar boundary-layer" by Collatz, G.J. et al., published in Agricultural and Forest Meteorology, 1991, 54 (2-4):107-136 and "Recent investigations into the lipoxygenase pathway of plants", by Gardner, H.W., published in Biochimica Et Biophysica Acta, 1991, 1084 (3): 221-239. These two papers were cited 885 and 443 times respectively. The years 1999 and 1992 were the second and third years for most citations, where the number of citations was 2079 and 1928 respectively.

The H index for the 1682 papers was 79, that is, 79 papers were each cited for 79 times. The 1682 publications cited 49557 references for an average of 29.5 for each paper. The most cited references were papers published from 1989 to 1997 and the earliest reference cited was published in 1783. The paper was titled as "Elect vegetaux ouvra" by M. Bertholon. The 1682 publications over the past 71 years were in 421 different journals. Thirty four journals each published more than 10 publications, which accounted for 45% of the total publications. Around 234 journals published at least one soybean physiology-related paper. Table 3 lists the top 20 journals with the greater number of publications. These 20 journals published 509 articles, accounting for 30.3% of the total. By far, most articles were published in Crop Science (67), the No. 1, most popular and favored journal for soybean physiologists to publish their papers, accounting for 4.0% of the total publications. This was followed by Plant Physiology (58) accounting for 3.45% of the total, Plant and Soil (32) accounting for 1.90%, Field Crops Research (31) accounting for 1.84%, Agronomy Journal (27) accounting for 1.61% and Physiologia Plantarum (26) accounting for 1.55%. Most of the other journals were related to agriculture. Eight out of the top 20 journals had impact factors over 3.0 and these eight journals were ranked the top 36 among the 196 plant science journals in the web of science database. For example, Plant Physiology ranked No.7 in the top 36 journals. Plant Physiology was also the most popular reference journal with 3 citations for each published paper relevant to soybean physiology. An expected result was that the majority of the top 20 journals were also the main sources of reference.

Table 4. Top 20 journals, sources of references and number of reference citation from 1943 to July, 2014.

Journals of publication	No. of publication	Impact factor in 2013
Crop Science	67	1.478
Plant physiology	58	7.394
Plant and soil	32	3.235
Field Crops Research	31	2.608
Seed science and technology	28	0.706
Agronomy journal	27	1.542
Physiologia plantarum	26	3.262
Weed science	24	1.684
Journal of experimental botany	23	5.794
Journal of plant physiology	22	2.77
Pesquisa agropecuara brasileira	21	0.676
Journal of agricultural and food chemistry	20	3.107
Journal of plant nutrition	19	0.536
Plos One	19	3.534
Plant cell and environment	18	5.906
Phyytopathology	17	2.746
Annals of botany	15	3.295
Environmental and experimental botany	14	3.003
New phytologist	14	6.373
Plant disease	14	2.742

Table 5. Most cited reference journals and number of reference citation from 1943 to July, 2014.

Journals of reference cited	No. of publication cited	No. of citation
Plant physiology	842	4743
Crop science	549	2338
Journal of experimental botany	496	1365
Proceedings of national academy of science, USA	442	969
Physiologia plantarum	435	1102
Planta	421	950
Agronomy Journal	395	1224
Journal of biological chemistry	381	1115
Nature	381	649
Science	361	639
Annual review of plant physiology	316	494
Plant cell and environment	308	727
Plant cell	291	1009
Plant and soil	288	771
Plant cell and physiology	269	511
Plant Journal	264	789
Annuals of botany, London	262	494
New physiologist	262	631
Plant molecular biology	239	615
Plant science	236	415

Conclusions

Since the first paper published in 1943 on soybean physiology in the web of science database, the area of soybean physiology research has experienced great changes and increase in scientific productivity. Up to July, 2014, 1682 articles have been published and most productive subject categories were nitrogen fixation, photosynthesis, growth, mineral nutrition, gene expression, genotypes, drought stress, yield and seed quality. The gene expression for quality and yield under drought stress conditions is now becoming a major topic for soybean physiology. Authors representing 76 countries were documented to have worked in soybean physiology issues and they were mostly distributed in North America, South America, Western European countries, China, Japan, Australia and India. T.R. Sinclair from the University of Florida/North Carolina State University and D.B. Egli from the Kentucky University were the most productive authors and USDA ARS, University of Illinois and Iowa State University published the most influential articles. The most productive journals were the Journals of Crop Science, Plant Physiology, Plant and Soil, Field Crops Research, Seed Science and Technology, Agronomy Journal and Physiologia Plantarum. The USA exceeded all other countries with the most independent and collaborative papers in research on soybean physiology. This was followed by Brazil (159), China (109), Japan (104), Australia (58) and Germany (58). Other countries with higher numbers in independent and collaborative papers are Canada (56), India (51), France (50) and Argentina (42). Eight out of the top ten productive institutions were located in the US. The past 71-years of research on soybean physiology has not only contributed a great deal to the understanding of the plant growth, development and physiological mechanisms involved in soybean plants, but also to the identification and establishment of cost-effective production practice, development of management systems as well release of several private and public soybean cultivars. New challenges may come, however, we are confident that soybean physiologists will continue to develop quality work and will serve the soybean production with skill, creativity and new innovations.

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