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Considerations on Crop Science and its Development

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Summary

"Crop science" along with an accepted definition of "science" may be generally defined as "the traditional existence of knowledge and the process of methodically performed, principally reproducible knowledge, elaborated by knowledge production." With regard to its content crop science is considered composed of the sub-disciplines eco-engineering, natural sciences and system science. For many decisions economic aspects also have to be taken into account. Knowledge production and its development in eco-engineering and system science is described primarily by research methodology, in natural sciences by the history of fundamental crop science related insights. Accumulated knowledge as a whole is estimated by analysing manuals on vegetable production in German language in the period of 1530 to 2003.

After a long precursor period crop science started in Germany about 1800, initiating a rapid development of experimental methodology and technical literature. From the middle of the 20th century onward a strengthened consideration of eco-physiological knowledge is observed, and from the end of the 20th century systems scientific knowledge. Thus both, quantity and quality of knowledge were expanded and improved, as well as its structure and presentation. The problems, limitations and consequences of this process are discussed.

Zusammenfassung

Betrachtungen zur Pflanzenbauwissenschaft und ihrer Entwicklung. Entsprechend einer anerkannten Definition der „Wissenschaft" wird auch die „Pflanzenbauwissenschaft" als „überlieferter Bestand des Wissens, und der Prozess methodisch betriebener, prinzipiell nachvollziehbarer Erkenntnisarbeit" definiert. Pflanzenbauwissenschaft beruht auf einem Kompositum aus Öko-Ingenieurwissenschaft, Naturwissenschaft und Systemwissenschaft. Sie hat bei vielen Entscheidungen auch ökonomische Aspekte zu berücksichtigen. Die Entwicklung der Erkenntnisarbeit wird für die Öko-Ingenieur- und Systemwissenschaft primär über die Forschungsmethodik, für die Naturwissenschaften über die Geschichte fundamentaler, pflanzenbaulich relevanter Erkenntnisse beschrieben. Das akkumulierte Wissen wird durch die Analyse von Gemüsebaubüchern in deutscher Sprache in der Spanne von 1530–2003 beurteilt.

Nach einer langen Periode der Wegbereitung wird der Beginn der Pflanzenbauwissenschaft auf etwa 1800 datiert. Sie löste eine rasante Entwicklung der experimentellen Methodologie aus, die ab Mitte des 20. Jahrhunderts von öko-physiologischem Wissen und seit dem Ende des 20. Jahrhunderts durch systemwissenschaftliches Wissen ergänzt wurde. Parallel verbesserten sich Quantität und Qualität des Wissens, seine Strukturierung und Präsentation. Die Probleme und Grenzen dieses Prozesses sowie die Schlussfolgerungen werden diskutiert.

Key words. crop science – vegetable science – special basic conditions – driving forces – experimental methodology – natural sciences – system science – knowledge production – vegetable manuals

Introduction

Many discourses are published on history of "crop production", but only few of them deal with the history and character of "crop science" (e.g. TORNOW 1958; BOGUSLAWSKI 1959; KRUG 1970, 1988; BÖHM 1985, 1988, 1990a; HANUS 1997). The scope of this paper is an approach to define, to analyse, to describe and to explain "crop science" (in terms of crop production science) in its agri-/horticultural, scientific and social environment. Due to the countless aspects, the regional historical developments, technically to the collection of a wide spread, difficult accessible literature and the translation from many languages, restrictions were inevitable. The author decided to concentrate on the global system and to restrict the considerations primary to the indicator "vegetable science" as reflected in German literature.

Definitions, Material and Method

Various definitions are offered for **science**. In the context of this topic the following definition is considered appropriate (according to Neuer Brockhaus, encyclopaedia of 1978–80): "The traditional existence of knowledge and the process of methodically performed, principally reproducible knowledge elaborated by knowledge production." For disciplines which work primarily with the "inductive method", as "natural sciences" do, knowledge production means: To collect, to structure, to analyse critically and to describe the material, to work out causal and stochastic relations, to parameterise these, to develop hypotheses and models, to test falsification and to develop theories.

Crop science at its beginning covered the entire field of crop production and can be defined as above,

referring to the disciplines which primarily work with planning and managing the crop production system (crop science in a broader sense). With specialisation, however, which occurred from about 1900 and especially in the twenties of the 20th century, all disciplines which have specialised, such as engineering, genetics and breeding, plant protection and others should be excluded (crop science in a narrower sense). The present contribution is restricted to the latter.

Since crop production is a complex system, covering various disciplines and problems, also crop science is composed by different sub-disciplines, consisting of:

- From ancient times onward it had and it still has to cope the task to collect, to compare, to select and to improve knowledge on procedures including the essential equipments, machines, tools and means in an ecological context, and to pass it to future generations. In this sense crop science is an **eco-engineering discipline**.
- Crop science, too, is a part of **natural sciences**: It aims at knowledge on fundamental relationships between genotypes and the ecologically prevailing environmental conditions and management effects. In this field it is based on methods and knowledge of biology, physics, chemistry etc.
- Crop science, just as other applied sciences, e.g. medicine, has to integrate the knowledge of all its components and external contributions to a holistic view, in order to elaborate a basis of understanding, predicting, planning and managing the complex and complicated system and to give impulses to basic disciplines to deal with open questions. For a few decades **system science** has offered appropriate approaches and tools for integration and is now developing to become an important component.
- In many decisions crop science has to consider the economic conditions, constraints and options. Therewith **economic aspects** (e.g. cost calculations, monetary return) have to be integrated.

As an applied science, crop science, too, has to process this knowledge for application in planning, management and control.

The **development** of a science may generally be defined as the history of ideas, methods, objects, persons and institutions (BÖHM 1985). In the context of this topic it is defined as the chronological development of knowledge production and rate of increase of accumulated knowledge as a whole in this discipline. Since this is a slow, long term and already at the beginning important, but not yet really scientific process, the course of development is divided to a precursor (preparatory) and a scientific period. The criteria used for knowledge production are those cited in the definition of science (first paragraph of this chapter). However, these can only be applied according to the level of methodology already reached.

The **material** (documents**)** for the analysis presented here are publications in journals, especially the journal "Gartenbauwissenschaft" ("Archiv für Gartenbau", published from 1953–1990 in the German Democratic Republic, is excluded) and appropriate manuals published in German language. Concerning the manuals in context with this evaluation, books describing special techniques or those only dealing with single species as well as papers from monasteries or decrees are not considered. The manuals evaluated are listed in Table 1.

The **judgement** to what degree the criteria are fulfilled is performed subjectively.

History and Character of Crop Science

Precursor period

The beginning of prescientific work can be traced back to antiquity, starting with Hesiod (740–670 B.C.), reaching its culminating period with Aristotle and Theophrast (4. century B.C.). Knowledge was collected, structured and described in several books (see JAHN 2000; KRUG 2003a). With respect to methodology this knowledge was produced by observing and reflecting with respect to a reasonable entireness, in general without experimental testing. Thus, it was speculative, does not meet the criteria for science claimed above and it can only be classified as a precursor. This view of nature governed Europe for nearly 2000 years until about 1600, concerning agri-horticulture at least about 1750.

An idea of the horticultural knowledge of those times may be reflected by the first book available in the German language of 1530 (Table 1). As common in that time, when books were primarily translated from ancient ones, the author is not indicated. It is centred to the "Hausväter" (family heads, as heads of holdings). Written in the "new high German" language this book gives an insight to the means, procedures and experiences of that time, but it is not well structured. Except some rather simple environmental considerations it only describes technical procedures and it is still penetrated with speculative as well as mystical/metaphysical components.

After the Cartesian Turn (about 1600) the physician in ordinary and Praefectus hortorum of the "Große Kurfürst" (Great Elector) in Brandenburg, J. S. ELßHOLTZ published "Vom Gartenbaw" (On gardening) in 1666 (the evaluated reprint is the 3. ed. in 1684). Elßholtz had studied medicine including botany and the antique as well as the actual corresponding German, French and Italian literature, a good basis for reviewing the knowledge of that time. His book contains profound descriptions of vegetable cultivation of his time. It is well structured and therewith distinctly advanced compared to the Anonymous of 1530. However, it still is not a critical consideration, it does not indicate methodical knowledge production, it is not looking for profound relations and lacks any botanical background, except the scientific names of those days. This book still contains some mystical/ metaphysical statements and errors. Although a new view of nature had already started to be established in natural sciences, the book of Elßholtz has to be regarded as a precursor, paving the way to crop science.

The first book meeting the criteria of a critical analysis and dealing with the methodical production of knowledge is "Christian Reicharts Land und Gartenschatz" (Chr. R. land and gardening treasure) (1753, 1754, 1755). Reichart (1685–1775) studied law, acted as a town-councillor in Erfurt, managed his own extended fields and gathered experiences on excursions and by studying literature. He is called one of the first "Ex-

Table 1. Vegetable, horticultural including vegetable and supplementing botanical manuals (in italic letters), arranged chronologically [( ) not the first edition; + based on English books, # based on French books; * not to obtain and therewith not evaluated; no claim for completeness].

1530	ANONYMOUS (1530): Lustgärten vnnd pflantzungen Mit wunnsamer zyerd. artlicher vnd seltzamer verimpffung aller hand Beum, Kreutter, Plümen vnnd früchten, Wylder vnnd heymischer, Künstlich vnnd lustig zu zürichten, Innhalt volgents Registers. Weß sich ein Hausuater mit seiner Arbeyt das Jar vber / Alle Monat inn sonderheit halten soll. Getruckt zu Augspurg durch Haynrich Stayner
1666	ELßHOLTZ, J. S. (1684): Vom Garten-Baw. Reprint Georg Olmsverlag Hildesheim, Zürich, New York, 1987. Ed.1. 1666 1. 2. 1672, 3. 1684, 4. (after his death) 1715
1693*	HOLYK, G. 1693: Dreifaches Gartenbüchlein
1750*+	BROWELL, S. (1750): Anleitung für einen Landmann oder Abhandlungen von dem Ackerbaue, der Gärtnerey und anderen merkwürdigen Dingen, welche die Landwirtschaft betreffen. Verlag Carl Ludwig Jakobi, Leipzig 1750. Translated from English, with own remarks, with an appendix of Wilhelm Ellis
1753	REICHART, Chr. (1753): Christian Reicharts Land und Gartenschatz. Teil 3. Von den zur Speise dienlichen Kohlen, Wurzeln und Zwiebeln, deren Erziehung und Wartung nach allen Stücken aufrichtig beschrieben worden. Verlag Johann Heinrich Nonne, Erfurt. Ed. 2. 1754, 3. 1755, 4. ?, 5. 1791
1758	REICHART, Chr. (1758): Einleitung in den Garten- und Acker-Bau. Teil I. Nonne Verlag, Erfurt
1780+	LUEDER, F. H. H. (1780): Vollständige Anleitung zur Wartung aller in Europa bekannten Küchengartengewächse – aus dem Englischen übersetzt und mit botanischen und praktischen Anmerkungen erläutert. Gedruckt von Chr. G. Donatius, Lübeck. (Compiled from Miller, Philip: „Gardens Dictionary", 8. ed., London 1768 and „The gardens calendular", 16. ed.; ed. 2. 1783
1818*	WREDOW, J. C. L. (1818): Gartenfreund oder vollständiger, auf Theorie und Erfahrung gegründeter Unterricht über die Behandlung des Bodens und Erziehung der Gewächse im Küchen-, Obst- und Blumengarten, in Verbindung... . Verlag Carl Friedrich Amelang, Berlin. Ed. 2. 1823, 3. 1827, 4. 1832, 11. 1864, 12. 1869.
1823	LOUDON, I. C. (1823, 1824): Eine Encyclopädie des Gartenwesens, enthaltend die Theorie und Praxis des Gemüsebaus, der Bienenzucht, Baumzucht und der Landschaftsgärtnerei. Verlag des Gr. Herzoglichen Sächs. Privil. Landes-Industrie-Comptoris
*1828# *	*THON, Th. (1828): Die Botanik in ihrer praktischen Anwendung... Gärtner. Druck B.F. Voigt, Ilmenau. Free translation from French*
*1839**	*DIETRICH, A. (1839): Botanik für Gärtner und Gartenfreunde. In: Lenné et al.: Handbibliothek für Gärtner und Liebhaber der Gärtnerei, Teil 3. Herbig, Berlin*
1843+	*LINDLEY, J. (1843): Theorie der Gartenkunde oder Versuch, die vornehmsten Operationen beim Gartenbau nach physiologischen Grundsätzen zu erklären. (Translation, 1843, Erlangen)*
1847	LUCAS, E. (1847): Der Gemüsebau. Verlag der Metzlerschen Buchhandlung, Stuttgart. Ed. 2. 1859; 3. 1871; 4. 1907: Anleitung zum Gemüsebau sowie zur Einrichtung eines Hausgartens: Zur Selbstbelehrung sowie als Leitfaden zum Unterricht für Haushaltsschulen und landwirtschaftliche Lehranstalten. Verlag Eugen Ulmer, Stuttgart. 5. „Anleitung zum Gemüsebau", 1913; 6. 1917
(1847)+*	*LINDLEY, J. (1847): Theorie der Gärtnerei (translation). Verlag Carl Gerold, Wien, 2. ed.; 1. ed. 1842*
1855	*REGEL, E. (1855): Die Pflanze und ihr Leben in ihrer Beziehung zum praktischen Gartenbau. Verlag Friedrich Schultheß, Zürich*
1856	KÖLLE, GEBRÜDER (eds., 1856): Der Ulmer Gemüsegärtner: Eine genaue Anweisung aller Gemüse, Salate, Gewürz- und Küchenkräuter zu ziehen nebst Anhang über Samenzucht. Verlag von Carl Hoffmann, Stuttgart
1857	JÄGER, H. (1857): Der praktische Gemüsegärtner I, II und III. Verlag Otto Spamer, Leipzig. Ed.2. ?, 3. 1871: Der Gemüsegärtner I. Allgemeine Lehre vom Gemüsebau, II. Kultur aller bekannten Gewächse, III. Die Gemüsetreiberei. Verlag Cohen und Risch, Hannover
1858	SAFTENBERG, F. (1858): Der praktische Gemüsegärtner. Ensslin und Laiblins Verlagsbuchhandlung, Reutlingen
1860	MEYER, I. G. (1860): Der rationelle Pflanzenbau. 7. Teil: Die Gemüsepflanzen. Verlag Enke, Erlangen
(1874)	JÄGER, J. (1874): Anleitung zum Gemüsebau im Allgemeinen und insbesondere auf Landgütern und in Dorfgemeinden. 2. ed., Verlag Otto Spamer, Leipzig
1874*	BOUCHÉ, J. (1874): Der Gemüsebau: Eine praktische Anleitung zur Erziehung und Kultur sämtlicher Gemüse und Küchengewächse. Schotten Verlag, Berlin
(1880)	USLAR, B. von (1880): Der Gemüsebau: Anleitung zum Gebrauche an Lehranstalten und zum Selbstunterricht. Verlag von Wiegandt, Hempel and Parey, Berlin. 6. ed.; 7. and 8. s. GOTT 1925, 1944
1882	STAEMMLER, F. (1882): Grundriß des Gemüse-Baues. Verlag Karl Scholtze, Leipzig
1884	GRESSENT, A. (1884): Gressent's einträglicher Gemüsebau: neue Anleitung auf kleinem Raum mit mäßigen Kosten, regelmäßig reiche Ernten in guten Sorten zu erzielen. Verlag Paul Parey, Berlin. Ed. 2 1884, 3 ?, 4. ed. by JANSON, A. 1918 , 5. JANSON, A. (1923): Einträglicher Gemüsebau, Paul Parey, Berlin.
1889	BÖTTNER, J. (1889): Praktische Gemüsegärtnerei. Trowitsch und Sohn, Frankfurt/Oder. Ed. 4. 1904, 7. 1913, 9. 1919, 11. 1926, 12. ?. BÖTTNER, J. (ed.) (1940): Erfolgreicher Gemüsebau. Gartenbauverlag Trowitsch und Sohn, Frankfurt/Oder, Berlin. Concomitant 13. und 14. ed. of Böttners „Praktische Gemüsegärtnerei"
1891	*SORAUER, P. (1891): Populäre Pflanzenphysiologie für Gärtner. Verlag Eugen Ulmer, Stuttgart*

(1898)	WINTER, A. (1898): Vollständiges Gartenbuch. 9. ed. Schulbuchhandlung von F. G. L. Greßler, Langensalza
ca.1900	WILKE, Th. (ca. 1900): Einträglicher Gemüsebau unter Berücksichtigung der Vor-, Zwischen- und Nachfrüchte. Neumann Verlag, Neudamm
1916	WAUER, O. (1916): Der Feldgemüsebau, ein Nebenbetrieb der Landwirtschaft. Druck Otto Elsner, Sprottau
1916	*MOLISCH, H. (1916): Pflanzenphysiologie als Theorie de Gärtnerei. Verlag Gustav Fischer, Jena*
(1920)	KUNERT, F. (1920): Hampels Handbuch der Frucht- und Gemüsetreiberei. 4. ed., Verlag Paul Parey, Berlin. 5. ed. 1923
1921	WEIRUP, E.and E. HARTH (1921): Gemüsebau. Verlag Paul Parey, Berlin
1924	BECKER-DILLINGEN, J. (1924): Handbuch des gesamten Gemüsebaues. Verlag Paul Parey, Berlin, ed: 2. 1929, 3. 1938, 4. 1943, 5. 1950, 6. 1956
(1925)	PAPE und BERGMANN (eds., 1925): Das beste Gemüse. 3. ed. Verlag Pape und Bergmann, Quedlinburg
1925	GOTT, W. (1925): Gemüsebau. Verlag Paul Parey, Berlin. Ed. 7. 1933, 8. 1944. Ed. 1–6 s. Uslar 1880
1926	MÜLLERS, L. (1926): Der Gemüsegarten. Volksvereins Verlag, München Gladbach
1927	KRATZ, H. (1927): Der Erwerbsgemüsebau, Verlag Eugen Ulmer, Stuttgart. Ed. 2. 1932, 3. 1941, 4. 1943, 5. 1949, 6. 1956 (further eds. s. FRITZ and STOLZ).
1931	REICHELT, K.and N. NICOLAISEN (1931): Die Praxis des Gemüsebaues. Verlag Paul Parey, Berlin
1937	MÜLLERS, L. (1937): Gemüsebau. Verlag Heinrich Killinger, Nordhausen.
1949	REINHOLD, J. (1949): Der Gemüsebau in der Zierpflanzengärtnerei. Fortschrittlicher Gartenbau 2, Dresdener Verlagsgesellschaft KG, Dresden
1950	REINHOLD, J. (1950): Der Gemüsebau als Zwischenfruchtbau in der Bauernwirtschaft. Fortschrittlicher Gartenbau 3, Dresdener Verlagsgesellschaft KG, Dresden
1951	KLETTE, G. (1951): Gemüsebau in der Praxis. Verlag Paul Parey, Berlin
1956	NICOLAISEN, N. (1956): Gemüsebau, zweckmäßig und lohnend. Verlag M. und H. Schaper, Hannover
1956	BIELKA, R. (1956): Feldgemüsebau. VEB Deutscher Landwirtschaftsverlag, Berlin. Ed. 3. 1965, 4. 1969
1957	BIELKA, R. (1957): Grundriß des Feldgemüsebaues: eine Einführung für Studierende der Landwirtschaft. Deutscher Bauernverlag, Berlin
1958	REINHOLD, J. (ed., 1958): Ratgeber für den Gemüsebau unter Glas. Deutscher Bauernverlag, Berlin. Ed. 2. Deutscher Landwirtschaftsverlag, Berlin 1963, 3. 1966, 4. (completely new written) DEHNE, J. (1969): Ratgeber für die Gemüseproduktion unter Glas und Plasten.
1962	REINHOLD, J. (ed., 1962): Ratgeber für den Feingemüsebau im Freiland. Deutscher Landwirtschaftsverlag, Berlin
1964	HÖSSLIN, R. Von, F. MAPPES and T. STEIB (1964): Gemüsebau, Erzeugung und Absatz. BLV Verlagsgesellschaft, München, Basel, Wien
1966	*RUGE, U. (1966): Angewandte Pflanzenphysiologie. Eugen Ulmer Verlag, Stuttgart*
1967	GEISSLER, Th., E. BAUMANN and Chr. FÖRTSCH (1967): Grundlagen des Gemüsebaues. Deutscher Landwirtschaftsverlag, Berlin. 2. ed. Geissler, Th.: Grundlagen der Gemüseproduktion, 1974, 3. 1978, 4. 1985, 5. 1985
1971	MÜLLER, H. and F. PREISING (1971): Unterglas-Gemüsebau. Verlag Paul Parey, Berlin and Hamburg
1973	FRITZ, D. and W. STOLZ (1973): Erwerbsgemüsebau. Handbuch des Erwerbsgärtners. Vol. 7, Verlag Eugen Ulmer, Stuttgart. Ed. 8. 1981, 9. 1989 (Vol. 1-6 see KRATZ 1927)
1975	EHRLE, L. (1975): Produktion von Qualitätsgemüse, Feldanbau für Industrie und Markt. Verlag Paul Parey, Berlin and Hamburg
1976	BIELKA, R (1976): Freilandgemüseproduktion. Deutscher Landwirtschaftsverlag, Berlin. Ed. 2. 1980, 3. 1986, 4. Bielka, R., Th. Geissler and F. Kaufmann 1988
1976	GEISSLER, Th. (ed., 1976): Gemüseproduktion unter Glas und Plasten. III. Produktionsverfahren. Deutscher Landwirtschaftsverlag, Berlin. Ed. 2. 1979, 3. 1981, 4. 1985, 5. 1988, 6. 1991
1977	VOGEL, G. (ed., 1977): Gemüseproduktion unter Glas und Plasten: Natürliche und materiell-technische Voraussetzungen. Deutscher Landwirtschaftsverlag, Berlin. Ed. 2. 1981, 3. 1987
1986	KRUG, H. (1986): Gemüseproduktion. Verlag Paul Parey, Berlin, Hamburg. Ed. 2 1991
1992	REINKEN, G. (1992): Integrierter Gemüse- und Obstbau im Europäischen Binnenmarkt. Verlag Eugen Ulmer, Stuttgart
1996	VOGEL, G. (1996): Handbuch des speziellen Gemüsebaues. Verlag Eugen Ulmer, Stuttgart
1997	*WIEN, H. C. (ed., 1997): The physiology of vegetable crops. Cap International, Wallngford Oxon, U.K. (with German Contribution)*
2003	KRUG, H., H. P. LIEBIG and H. STÜTZEL (2003): Gemüseproduktion. Verlag Eugen Ulmer, Stuttgart

perimental Economists" (in that time agriculture was called "economy"). Especially his scrutinising, critical view, his methodical procedure, his comprehensive knowledge and his admirable activities are remarkable.

Reichart, however, was not as advanced, not as consistent and – compared to the bigger sister agriculture – not as effective and well known as the physician A. Thaer (1752–1828), about 50 years later. With his book "Grundsätze der rationellen Landwirtschaft" (Fundamentals of rational agriculture, 4 volumes from 1809–1821), with the foundation of the first Academy of Agriculture in Prussia and as a Professor for "Kameralwissenschaften" (precursor of agricultural science) at the Berlin University (1810/1), Thaer is considered as the "father of crop science" in Germany. Therefore about 1800 is set as the starting point of crop science.

Crop science period

The development of science is the result of numerous driving forces, which act and interact from outside and inside the respective discipline. Forces from outside can be summarised as "special basic conditions", like forces from natural sciences, economy, technology, policy, society etc..

Special basic conditions. Special basic conditions for crop production and crop science are described among others by KRUG (1997, 2003a) and can be summarised as follows (literature see KRUG 2003a):

- About 1268 establishment of horticulture as a profession (first guild of growers in Basle).
- About 1560 first reports on horticultural holdings; first greenhouses.
- About 1600 the "Carthesian Turn" in thinking that means the turnover from the antique (Aristotle) and the Middle Ages world view to the mechanistic one.
- In the second half of the 18th century new, revolutionary technical inventions, beginning of methodical crossings in plant breeding, establishment of special firms for breeding and seed production in Germany (Quedlinburg and Erfurt), first horticultural journals for extended communication, establishment of the "Kameralwissenschaften" at universities.
- In the 19th century explosion of the population with misery, especially famine, emigration, exerting pressure on agricultural productivity, paralleled and followed by a boom in technology and economy, the so called "Industrial Revolution". This gave rise to factories producing agri-/horticultural machinery and tools, such as sowing machines, the steam plough (1849), iron founded greenhouses; 1824 the foundation of the first "Horticultural School" in Berlin; 1863–1923 establishment of some 65 agri-/horticultural research institutions and schools in Germany; agricultural and horticultural associations; a new type of universities (Humboldt-type-University) with specialised disciplines in natural sciences, such as chemistry, agricultural chemistry including nutrition physiology (about 1840, more particulars in KRUG 2003a); the establishment of the discipline phytopathology (1858) as well as plant physiology (1865).
- In the 20th century teaching of horticultural science at the University of Berlin (1929), the establishment of an advisory service (JÜRGENSEN 1984), intensified plant breeding on a genetic basis, motorisation and general mechanization, employment of agrochemicals for plant protection, fertilisation and chemical growth regulation, new synthetics (e.g. plastics), globalisation of marketing and information, followed by the electronic revolution.

Knowledge production. The driving forces for knowledge production can be classified as coming from the sub-disciplines eco-engineering, natural sciences, system science, economics and respective disciplines besides crop science. Knowledge production in eco-engineering is characterised by multifaceted questions and results, but by a rather continuous methodology, the field experiment. Therefore methodology is used for characterisation. Knowledge production in natural sciences and system science are closely connected with their central disciplines. Concerning natural sciences it is characterised by multifaceted methods, but – as far as crop science is concerned – by outstanding results to understand and control plant life. Therefore, in this sub-discipline knowledge production is analysed in close connection with respective advances in its central discipline. In system science, again, methodology ranges first.

Eco-engineering

- *Empirical knowledge*, accumulated by doing and observation, checked by numerous users, by long time application and exchange of information. It was the only driving force at the beginning and, though not scientific, it is still important and rather reliable, as long as the special basic conditions outside and the conditions inside the production system do not change markedly.
- *Experimentally produced knowledge*, acquired in experiments and in research under the respective special basic conditions. It is released by questions within and beyond production, new challenges and inventions in natural sciences or techniques, developments or offers and restrictions, respectively, within and beyond the discipline. Using adequate methods experimentally produced knowledge yields reasonable results at least for the conditions of the experiments. Problems may arise by working with simplifications (e.g. experiments in greenhouses, growth chambers, pots) and by changing special basic conditions.

Results of both categories flow into in the eco-engineering knowledge and cannot really be separated. As experiments are considered the main driving forces, the development of knowledge production is described by the development of experimental methodology:

A main tool for knowledge production was and still is the **field experiment** (including greenhouses and other equipment's); later on it was supplemented by laboratory research. Field experiments of the "*try and cut*" type, considering the crop as a "black box", started in the middle of the 18th century (REICHART 1753, ECKHART 1754). In the beginning field experiments mostly were simple plots, without replications, to compare treatments or cultivars, but soon some more sophisticated approaches occurred (BÖHM 1990b). Methodology was improved continuously and was almost perfected in the 1960th.

Remarkable steps are:

- Variation of one factor under different climatic or edaphic conditions, keeping controllable others constant, without replications in the respective trial, as described in "Philosophie und Methodik der Feldversuche" (philosophy and methodology of field experiments) in the book "Grundsätzen der rationellen Landwirtschaft" by THAER (1809).
- Stimulation of experimentation in the second half of the 19th century by the controversy on mineral nutrition and fertilisation [Sprengel (1787–1859) and Liebig (1803–1873), see BÖHM 1990b]
- STÖCKHARDT (1858) claimed for replications for each trial.
- Activities of the 65 agricultural experiment stations in Germany, founded from 1863 to 1923.

– In the second half of the 19th century pot experiments (reviewed by KÜHN 1972) and sand cultures as well as nutrient solution cultures (reviewed by JUNG 1972) in the open, in "rain-out-shelters" or in greenhouses gained importance.
– First approach to obtain statistic significances (MAERKER 1880). RODEWALD (1907) suggested to introduce the "theory of probabilities" into agricultural experiments, since biometric approaches were developed by Galton and Pearson at the turn from the 19th to the 20th century (cit. acc. SCHMETTERER 1961).
– ROEMER (1920) published the booklet "Der Feldversuch: eine kritische Studie auf naturwissenschaftlich-mathematischer Grundlage" (The field trial: a critical study based on natural-science and mathematics).
– Advanced biometric methods were introduced by FISHER and YATES (1938). In Germany biometrisation of agricultural experimentation was initiated in the 1950ies and 1960ies (survey by BEHRENS 1972). In 1953, Bielka published basic investigations on plot size, border effects and the influences of neighbouring and missing plants in vegetable experiments. A general survey on the history of field experiments was presented by BOGUSLAWSKI and SCHUSTER (1972).

After precursors, such as the "temperature sum concept", developed first by RÉAUMUR (1735) and CANDOLLE (1855, reviews by WANG 1960) and first considerations on functional relationships between environmental factors and yield by TURGOT (1766, review in BOGUSLAWSKI 1972), at the beginning of the 20th century pathbreaking approaches were published regarding **parameterisation**, to quantify plant growth and plant-environment relationships. MITSCHERLICH (1909, 1919) and his team related yield or total biomass to varied intensities of single input factors, such as mineral elements, climatic, edaphic or management factors by a mathematical equation. The "Wirkungsfaktor" (effect coefficient) "c" indicated the effect of the corresponding input factor and allowed for management or economic deductions (review by BOGUSLAWSKI 1972). Growth functions were deduced (review by BOGUSLAWSKI 1972, functions see KRUG 1997 table 4.4) and a growth analysis allowed for deriving efficiency factors (e.g. Absolute Growth Rate, Mean Growth Rate and Relative Growth Rate). Global growth was dissected into growth components, such as Net Assimilation Rate, Leaf Area Index and others (BLACKMAN 1919 a. o., reviews by RICHARDS 1969; HUNT 1978).

Using correlation and regression calculations, developed by the Pearson-School about 1900, BROUWER (1926) studied statistically the effects of several simultaneously acting climatic factors on yield in open fields. He failed due to the complexity and confounded correlations. A new impact was given by technical achievements to vary the intensities of climatic factors more or less independently by air conditioning in phytotrons (WENT 1957) and – less perfect – in climate controlled greenhouses. These experiments enabled to entangle multifactorial relationships and by parameterisation mathematical description of multifactorial effects on crop growth and development by developing growth models at high abstraction level (e.g. KRUG and LIEBIG 1979, 1988, 1994). Towards the end of the 20th century the electronic revolution spread into agri-/horticultural experimentation, opening new potentials to measure, to register, to compute huge amounts of data and graphical design, enabling new procedures, such as weed control by image processing as well as to analyse, to simulate and to control complex systems, such as plant production.

Natural sciences

The natural sciences are tools to develop new or improved cultivation techniques, such as cloning and growing germplasm by tissue culture to produce e.g. somatic seeds (the revolutionary potentials of biotechnology, starting in the fifties of the 20th century, are described by MCCOWN 2003); to control growth and developmental effects, such as photoperiodism, vernalisation and dormancy or to control morphogenesis by growth regulators. Branches of natural sciences are helpful to understand, to avoid or to cure disorders, such as deficiencies, toxicities, cold injuries, senescence and others. They can be used to improve crop engineering techniques, such as planning, managing and control of crop production; they can be used to reduce harm to the environment or to the consumer by understanding the fundamentals.

This component of crop science is closely related to the development of the natural sciences, especially botany. History of botany is summarised by MÖBIUS (1937); MÄGDEFRAU (1992); JAHN (2000) and others. Main events are:

The first fundamental system of *taxonomy* was established by LINNÉ in 1707. It was early accepted by most of the authors of vegetable books and used for identification and partly for classification of species.

Morphology, after precursors, such as the "Kräuterbücher" (herb books) by Brunfels (*1458), Bock (*1498), Fuchs (*1501), Camerarius (*1626) or Kniphof (1733–1747), was established as a university discipline at the end of the 18th century. Literature on morphological and anatomical considerations was published in horticultural orientated botanical books, listened as "horticultural botany" by DOCHNAHL (1861).

First relevant *physiological publications* on photosynthesis and respiration were published by Priestly in 1779 and Ingen-Housz in 1780 and 1796, a paper on plant nutrition by de Saussure in 1804. As a university discipline plant physiology in Germany was established by Sachs (1865) and Pfeffer (1881). In Germany horticultural related botany including physiology was offered by THON (1828): "Botany in its practical application...and horticulture"(original titles see Table 1). In 1839 DIETRICH published "Botany for gardeners and garden-friends" and in 1843 LINDLEY, the great botanist and horticulturist in England, published a profound discourse on the botanical background of horticulture, translated into German. In Switzerland appeared in print the profound scientific book "The plant and its life in relation to applied horticulture" by REGEL (1855). In Germany wrote SORAUER (1891) "Popular plant physiology for gardeners" and MOLISCH (1916) "Plant physiology as a theory of gardening" (Table 1 in italics).

System science

Besides the common fundamental and applied research some scientists (e.g. NICOLAISEN 1954) regarded **integration** of knowledge from inside and outside the crop

science system as a main challenge. At that time the basic question was to integrate as much as possible the current factors affecting the production process. Later on the focus was extended to the whole process chain of production, that means starting with the genotype, the seed, cultivation, harvesting, processing up to marketing, including environmental and consumer effects.

Until the end of the 20th century and even now this was and is performed primarily subjectively. With specialisation, starting at the end of the 19th and increasing in the 20 years of the 20th century, this procedure became more and more complicated and it became obvious that integration of non-quantified and non-parameterised knowledge is extremely limited. Therefore methods for parameterisation and mathematical integration had to be developed, which became known under the keywords "modelling" or – in a more comprehensive sense – "system science".

If the approaches already described under "parameterisation" as well as the first approaches in ecology in the twenties of the 20th century (see Jahn and Sucker in JAHN 2000) are considered as precursors, the first studies on mathematical-physiological models in biology (metabolism in cells by RASHEVSKY) started about 1926 (SCHMETTERER 1961). Wiener aroused much attention by his book "Cybernetics" in 1948. BERTALANFFY (1968, 1995) extended, completed and summarised the different approaches to the "General System Theory". In the field of crop science and eco-physiology the model "Elcros" of DE WIT and BROUWER (1968) has to be considered as the starting point of system scientific approaches.

Subsequently the number of publications increased about exponentially, following two lines: Following the Mitscherlich approach, descriptive *Multiplicative Regression Models* were developed at high abstraction level on the basis of multifactorial experiments in greenhouses. These were partly supplemented by experiments in growth chambers and fields, with varied and – as far as possible – controlled intensities of essential climatic growth factors. The parameters were used to calculate Mean Growth Rates for separate growth phases or for total growth periods to compute the duration of growing periods as a function of the intensities of growth factors, of season, transplant and/or harvest weight and others (KRUG and LIEBIG 1979, 1988, 1994). These parameters were also used to calculate factor quantities (e.g. energy (RATH 2003) and CO_2 consumption) and their cost for decisions in control and "optimisation". Relative Growth Rates allowed for simulation growth curves. Surveys on the use of regression models in vegetable production are presented by KRUG (1997, 2003b). This black box or phenomenological approach can be extended and lightened by modelling with growth components (such as Net Assimilation Rate, Leaf Area Index, Leaf Weigh Ratio, Specific Leaf Area) or coupled with Mechanistic Submodels (ALSCHER et al. 2001). Problems of decisions making on the basis of phenomenological models are described in KRUG (2003c).

Physiological-dynamic, mechanistic models were developed at low abstraction level (reviewed by PENNING DE VRIES 1983; CHARLES-EDWARDS et al. 1986; THORNLEY and JOHNSON 1990; HEUVELINK 1996). These approaches are excellent to understand and to describe physiological relations, they can be used to simulate growth in short periods and they are useful tools to disclose gaps of knowledge. Due to insufficient knowledge, the huge number of parameters, the high degree of interactions, an unconsidered rest complex and error multiplication they are less suitable for planning and long term simulations and therewith long term control of plant growth. A special problem of modelling at low abstraction levels, to structure the hierarchical order of different processes (plant, organ, tissue, cells and so on), is discussed by THORNLEY (1980).

Most promising in field crops are models combining growth and development modules at low and high abstraction levels (BOOTE et al. 1996) with ecological modular subroutines simulating environmental subsystems, such as soil water balance, soil N-balance, soil organic matter-balance, residue dynamics, pest and disease damage etc. (BOOTE et al. 2002). Such growth models can be adapted to various species or cultivars. They can also be used for hypothesising genetic improvement of cultivars and for evaluating crop and soil management strategies.

Problems of valuation

The sub-disciplines of crop science emphasised cannot be demarcated distinctly. Empirically and scientifically produced elements interact with each other, together they are synergistic and the knowledge acquired in these components flows into the engineering component. Therewith the question arises, whether the **criteria** defined for natural sciences are appropriate for the applied discipline "crop science". Concerning the engineering component for "empirical knowledge" only the first four criteria (until "description") are appropriate. "Experimentally produced knowledge" covers a broad spectrum, from answering simple questions up to modelling and developing theories. Correspondingly the criteria can be extended from "describing" to the full claim. A similar situation exists for the natural sciences component. The system science component covers a more sophisticated field, the criteria mentioned above should be fulfilled at least until "falsification".

Reflectance of knowledge production in horticultural journals. According to ZANDER (1952) the first horticultural journal in Germany was published in 1783. In the bibliographic summary of DOCHNAHL (1861) the first writing in the chapter "Vereins- und periodische Schriften" (societies and periodical writings) dates back to 1777. Until 1800 13 writings concerning horticulture are cited, followed by a drastic increase until the end of the inquiry (1801–1830 = 22, 1831–1850 = 64, 1851–1860 = 40). This parallels the beginning of experimentation and indicates an increasing concern of horticulturists and other interested people in horticultural knowledge. An intensified exchange of information had started, dealing mostly with general or engineering questions.

The first scientific journal for horticulture in Germany is "Gartenbauwissenschaft" (Horticultural Science), issued 1929 with the establishment of horticulture as a university discipline and continued in 2003 as "European Journal of Horticultural Science". In Gartenbauwissenschaft about 529 papers were published in the field of vegetable science, until 1969 3,7 per year,

from 1970 to 2002 12 per year. The slow start is due to the young, just established discipline and to the consequences of the war (1939–1945) and post war difficulties. Especially from 1970 onward a high research intensity is obvious.

Classification into subdisciplines is difficult due to demarcation and overlapping problems. An approximate association, however, may be presented by a general survey. The overwhelming partition of 57 % of the papers is devoted to physiological questions or has at least a strong physiological component (without nutrition), 16 % is devoted to the topics nutrition and fertilisation, likewise 16 % to engineering topics, 6 % to modelling, 3 % to methodological and 1 % to morphological/anatomical questions. The high portion of natural scientific papers indicates the increasing potentials and the number of interested people in this field and an increasing interest to understand and improve cultural techniques. Some scientists working in this field considered physiology as the main, others even the only scientific field of horticultural research. The relatively low portion of eco-engineering topics can be explained by saturation effects and/or by publications in more applied journals. Modelling is just coming up. Methodology was and apparently still is not a main field of interest in horticulture.

The time course of partitioning of the subdisciplines shows an about equal part of engineering topics over the whole period analysed. The same is true for nutrition and fertilisation, except the seventies years with a higher rate of publications. Physiological questions show an absolutely distinct increase from 1970 onwards. The topics enclose radioactivity (since 1929), CO_2-enrichment (since 1929), photoperiodism (since 1931–13 years after discovering, thereafter frequently worked with), artificial lightening (since 1935), growth regulators (since 1939, more frequently in the seventies), vernalisation (since 1944, 34 years after discovering, intensified since the seventies), air pollution (since 1956) and others. Methodological questions and mathematisation show – after the approach of REINHOLD (1931) to mathemise growth curves and the basic research of BIELKA (1953) on field experimentation – some accumulation in the seventies and eighties, modelling research from 1979, more pronounced from 1984 onwards.

Reflectance of knowledge accumulation in manuals. To estimate the entirety of accumulated knowledge in a complex discipline is extremely difficult, if not impossible. Handbooks are not available in vegetable science (the "Becker-Dillingen" and "Vogel" are titled handbooks and are rather comprehensive, but they do not cover the entirety of knowledge). Reviews in journals are scanty or not at all existent. Journal articles are problematic, due to the numerous objectives and the topicality of questions in such a composed, comprehensive and complicated field.

Therefore *manuals* remain a suitable source. A main problem was to choose respective criteria to describe the extent and the development of the discipline, since it has to be considered that each epoch has its special challenges, such as the changeover from primarily home gardening to commercial production, the changeover from maximising yields to maximised quality and/or profitability, from sustainable production and local markets to global markets with free competition, low prices, high wages and restrictions with respect to the environment. These challenges cause accentuation of actual topics and disregard of traditional subjects. Moreover there is a broad spectrum of authors with different abilities, activities, experiences and interests and, also, the broad spectrum of addressees, ranging from the beginner to the professor or specialised researcher. The advantages of manuals, however, are to give a broad overview, to cover a long period and to be manageable. Therefore manuals are used for evaluation. Criteria are the chronological frequency of the first and the following editions, the fields covered and the content presented, volume and structure, always in context to the special basic conditions.

The first manual for horticulture in German available to the author was issued in 1530 (Table 1), 262 years after the establishment of the first guild of growers in Basle, considered as the beginning of horticulture as a profession, 80 years after the invention of printing, at the beginning of a great awakening, called renaissance, but before the turnover from the "empiric-speculative" to the "empiric experimental" period (about 1600). A rather comprehensive knowledge on horticultural engineering had accumulated in the several thousand years, but – as mentioned above – theoretical thinking and a critical view are missing and the manner of handling and presentation is insufficient.

About 200 years later, with the beginning of revolutionary turns in techniques, in natural sciences and in agri/horticulture practice, a remarkable increase in publications and information in vegetable cultivation started. The books cited by DOCHNAHL (1861) in his chapter "Küchengärtnerei" (kitchen horticulture) are listened in Table 2. As far as the author can evaluate, the knowledge presented ranges from simple observations to incidental ecological considerations, but predominantly dealing with practical engineering problems. The progress in knowledge in this period was still low and – measured in agricultural crops – reflected by a slow increase in yields. Rays of hope were the books of ELßHOLTZ (1666) and especially of REICHART (1753, 1758) as precursors of crop science.

Table 2. Number of published books per year concerning vegetable production topics (1) and vegetable production as a whole (2), cited by DOCHNAHL 1861, [(2) is included in (1)]

Period	(1)	(2)
1750–1800	0,9	0,16
1801–1830	2,3	0,73
1831–1850	3,3	0,75
1851–1860	3,2,	0,80

A notable rise in manuals for vegetable cultivation took place with the Industrial Revolution, paralleled by a revolution in research, teaching and science in general in the middle of the 19th century. From 1847 to 1871 four remarkable issues were published: LUCAS (1847),

JÄGER (1857), SAFTENBERG (1858) and MEYER (1860). All four books give a broader, more comprehensive and better structured survey on advanced production techniques compared to the precursors. They include the progress in knowledge in plant nutrition and fertilisation, but – despite of the already offered horticultural/botanical literature and the issue of LOUDON (1823, translated from English) with an excellent treatise on the botanical background of his time and on many other fields of horticulture – only SAFTENBERG and MEYER presented a short up dating physiological background.

A next advancement becomes obvious by BECKER-DILLINGEN`s "Handbuch des gesamten Gemüsebaues" (Handbook of total vegetable cultivation, 6 issues from 1924–1956) with an even more comprehensive and precise description of production techniques (1. ed. 1924, 1065 pp.) and more scientific background. He reported extensively on the origin and taxonomy of many species and was the first (except LOUDON 1823) who really paid attention to morphology. He reported on chemical composition and human nutritional effects of vegetables, but physiological aspects, were mentioned only scarcely. Also in his later editions processes such as photosynthesis, vernalisation (known since 1910), photoperiodism (known since 1918) are not mentioned. This book was considered the classic German book on vegetable science for about 40 years. The widespread issues of KRATZ (1927), however, in their first five editions, were still orientated only to the engineering component.

In East Germany (GDR), with the traditional German centre of horticultural research and education, the "Becker-Dillingen", was replaced by the "Reinhold-Geissler-School", presented also by Bielka, Vogel and others (see Table 1). These books with different titles and in several editions presented vegetable production on its scientific basis profoundly and actualised to the socialistic economy, stressing nutrition and fertilisation at a high standard, chemical composition, techniques and production procedures. Despite of its increasing attention in journals the physiological background is described only in brief or not at all.

In West-Germany (BRD) HÖßLIN et al (1964) presented a good description of West German production procedures, stressing the indispensable economic aspects in a free market, but natural scientific aspects are described scarcely or very generally. In FRITZ and STOLZ (1973, 1981,1989), the 6th–8th editions of KRATZ (1927), the botanical background of vegetable cultivation is more distinctly accentuated than in the preceding editions, than in Hößlin et al. and in the Reinhold-Geissler-School, but still rather short. An approach to present vegetable production in an eco-physiological perspective is the "Gemüseproduktion" (vegetable production) by KRUG (1986, 1991, KRUG et al. 2003). All manuals following "Becker-Dillingen" are less voluminous, but this is no indication of less knowledge, but was caused by the options of the authors or the publishers.

An exceptional position takes the comprehensive (1127 pp.) book "Handbuch des speziellen Gemüsebaus" (Handbook of special vegetable cultivation) of VOGEL (1996), a good reference book for a numerous number of species and their production in Central Europe, but not for general production aspects and their basis.

In vegetable manuals until now only KRUG (1986, 1991, KRUG et al. 2003) considers *system scientific approaches* and use them as tools to understand, to plan and to control crop production. More attention to this new field is given by eco-physiological books, such as the ones by LOOMIS and CONNOR (1992, 1998) and VARLET-GRANCHER et al. 1993).

In the German economy approaches to book-keeping can be traced back to the 13th century, others consider the turn from the 19th to the 20th century as the establishment of business economics (s. BOKELMANN and LENTZ 1997). In vegetable manuals REICHART (1753) considered productivity of labour and economic efficiency and it was a main topic by THAER (1809, 1810, 1821). In vegetable books LUCAS (1871) and GRESSENT (1884) present economic calculations, MÜLLERS (1937) refers to economic aspects and later on both, East- and West-German authors, especially HÖßLIN et al. (1964), deal with economic calculations. This is not the case for MEYER (1860), JÄGER (1871) and BECKER-DILLINGEN (1924 to 1956), for example, in whose books economic considerations are lacking. Since the middle of the 20th century specialised economic books were offered (e.g. STORCK 1969), discharging the production orientated manuals.

Reviewing Thoughts and Conclusions

For millenniums mankind managed crop production according to traditional and slowly improved rules. Progress was accordingly slow. Distinct progress was not achieved until after the Cartesian Turn men started to look methodically and critically for new, consolidated insights, for alternative actions and to collect, to structure and to pass down the accumulated knowledge not only orally, but written in wide spread publications. This was the birth of crop science.

From this time onwards, supported by improved special basic conditions in terms of a general boost and increase in prosperity with new cognition's and inventions in science and technique, an active period of experimentation had started: In Germany in the second half of the 19th century. It resulted in continuously improving methodology, accompanied by the development of technical literature in journals and manuals. New offers in materials, techniques and breeding were accepted quickly, offers by natural sciences, particular plant physiology, were accepted in vegetable science with hesitation or for a long time not at all. Even theorisers had difficulties to change from more or less fixed facts and rules to new insights.

This, however, is a main challenge of the future. Further on we have to verify old rules and to expand them by methodically assured knowledge. Beyond that we have to extend the questions, to replace the black boxes by models and to elaborate a more holistic view. This means to understand comprehensive, complex, dynamic processes of crop-environment relations, such as process chains from seeding to the product or even long term rotations with the dynamics of e.g. water, minerals and yielding. As far as possible, we have to develop methods for on-line information on the actual state and dynamics of the components of the system for planning and on-line controlling including feed-back information.

The goal is to move towards "precision farming" in favour of yields, economics, environment and the consumer. This requires more emphasis on basic research in crop science and an even closer connection with respective basic disciplines, especially ecology, system science, information technology and may be also biotechnology. This, too, requires a broader scientific basis and to stress more abstractly, logical, integrating thinking in education, research, advice and practice than in the past.

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Further references are provided on table 1.

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