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# Agricultural sciences in transition from 1800 to 2020: Exploring knowledge and creating impact

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ABSTRACT

Transitions in agricultural sciences are brought about by incorporating new findings and insights emerging from biological, chemical and biophysical sciences, by more advanced ways of experimentation and last but not least by quantitative methods and models for data analyses and processing. Major breakthroughs occurred from 1800 onwards when new insights on photosynthesis and mineral nutrition were incorporated in the theory on the growth of crops. It took almost half a century before the humus theory was replaced by a more sound theory on mineral nutrition. The publication by Darwin on domestication in 1868 and the rediscovery of Mendel's laws in 1900 gave a boost to genetics underlying classical plant and animal breeding, which was mainly based on crossing and selection. A major accomplishment of the evolutionary synthesis was the compatibility of Mendelian inheritance with Darwinian natural selection. The discovery of the DNA-structure in the mid-fifties of the 20th century on modern plant breeding showed already impact within some decades. To assess the wide diversity of plant traits for the performance of plants in yield and quality of the produce advanced phenotyping method under controlled conditions has become popular. Genome-wide selection for environments with multiple stresses, however, does require phenotyping in situ. Since 1800 the transition from observations on the plant, field and farm towards dedicated experimentation took place. During the 19th and 20th century the methods for experimentation and data analyses were strongly improved. It took until the mid-20th century before the importance of experiments under controlled conditions was recognized. Studies of plant processes under controlled conditions provided the building blocks for mechanistic modelling of crop growth and production. A systems approach combining knowledge at different scales and incorporating cutting-edge findings from the basic sciences into applied sciences will become important for making a great leap forward in developing agricultural science with impact. Transitions in agricultural research will continue to depend on progress made in the related basic sciences and the capacity for agricultural research and innovation. Therefore, an adequate public funding is required to maintain or even accelerate progress in sciences. This requires the support of the public at large. Public–private partnerships will be needed to bridge the gap between science and innovation.



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## 1. Introduction

Agricultural science developed in the Arab, Asian, Greek, Maya and Roman cultures based on empirical insight and the wisdom of people (e.g. Cato, 234–149 BC. "*De AgriCultura*"). Famous are the intricate irrigation systems of at least 2000 years ago. Without written documents and oral communication agricultural methods, tools and infrastructure would not have been developed. The evolution from primitive to modern farming systems in Europe was described by various authors (Zadoks, 2013). Mediaeval Europe (11–14th century) shifted from the subsistence agrarian economy to one where spatially dispersed trade in agricultural commodities could support societies that devoted resources to develop monastic institutions and cultural works in cities (Fraser, 2001). The relationships between agricultural revolutions and socio-economic developments during the period from 1450 to 2010 were studied by Moore (2010). He concluded that capitalist agencies pioneered successive agricultural revolutions, resulting in food surpluses. However, around 1800 a family of the working class in Berlin spent about 73% of their household budget on food of which two-thirds on bread (Braudel, 1979). Thus, during periods of political turmoil there was always a looming food crisis. With the growth of cities more food than the subsistence level of the farming community had to be produced. Progress in agricultural research took place much later than the modernization of sciences in general. A giant in the modernization of science has been Isaac Newton with his publication of the *Philosphiae Naturalis Principia Mathematica* in 1687 (Janiak, 2012). He was the first scientist to develop new concepts on space and time. Newton stressed the importance of theory and experiment. It took until about 1800 before systematic experimentation was introduced in agricultural sciences. The development of agricultural sciences has been shaped by societal needs and demands on the one hand and by knowledge provided by basic sciences. Some trends in society and science are presented in Table 1.

In this review major events affecting the content and course of agriculture science during the period from 1800 to 2000 are presented and discussed. The hypothesis is that major transitions in agricultural science were built on new insights in basic sciences. This applies especially for chemistry, physics, biology and mathematics. Chemistry played an essential role in the development of new theories on plant nutrition (Van der Ploeg et al., 1999), chemical regulation of growth (Davis and Curry, 1991), inventing the DNA structure (Watson and Crick, 1953), and a better understanding of food quality and safety (Friedman and Mc Donald, 1997). The role of physics has been essential in developing theories on photosynthesis (Farquhar et al., 2001), crop geometry and light use (Leuning et al., 1995), and on soil structure and processes (Jury et al., 2011). The role of biology in developing new insights on crop phenology, pest and disease incidence, and more recently the applications of molecular and cell biology in plant breeding (Stamp and Visser, 2012). Last but not least mathematics played a role in the development of statistical analyses and mechanistic modelling (De Wit, 1968). The objective of this review is to evaluate the boundaries and characteristics of major breakthroughs in agricultural sciences in the past (19th and 20th century) and present (21th century). Furthermore, an outlook is presented on future developments in agricultural sciences based on the present developments.

## 2. Agricultural sciences in the 19th century: exploration and invention

In the 17th century various theories existed already on how plants were fed by the soil. The role of water and manure was already known for centuries. However, a variety of theories existed on the uptake of salts, 'juices' and even soil particles by plants. The pioneer studies by Priestly in 1777 and Ingen-Houszin 1780 on leaf photosynthesis laid the basis for understanding the role of carbon dioxide assimilation by plants. These new insights were published in a book "*Recherches chimiques sur la vegetation*" (De Saussure, 1804). New findings were conflicting with the dominant theory at that time – the "*Humus Theory*", strongly defended by Albrecht Daniel Thaer among others at the beginning of the 19th century. The German agronomist Thaer became well-known through his books in which he published results of large scale field experiments carried out in a systematic way to underpin the conceptual framework of "*rational agriculture*" (Feller et al., 2003). He developed a scale to rate the production function of soils taking into account cropping system and nutrient requirements of crops. The production value ranged from 1514 to 5942 units for farming systems varying from purely arable (triennial rotation including fallow) to mixed farming including pasture. The most productive system turned out to be based on keeping cattle in the stable to maximize recycling of nutrients by manure applications on arable land. Thus, he choose already an integrated approach on the sustainable use of nutrients by considering recycling as an integral part of mixed farming: combining land use, arable cropping and cattle farming (Thaer, 1809). The "*Mineral Theory*" was developed by Sprengel and later widely published by Liebig during the 19th century (Van der Ploeg et al., 1999). It was clearly demonstrated that plant nutrients were taken up by the plant as mineral components. The new theory did boost the experimental work on nutrient uptake by crop plants. Most well-known is the initiative of Gilbert and Lawes in 1843 to start large long-term field experiments at Rothamsted (UK) to study the effects of the use of fertilizers and manure on soil fertility, biomass production and crop yield (Jenkinson, 1991; Rasmussen et al., 1998). The research on the famous Broadbalk fields contributed strongly to the understanding of the effect of management (manuring, fertilization, rotation, weed, pest and disease control, etc.) on the response of crops to nutrients. From the theoretical perspective the Law on Diminishing Returns and the Law on the Limiting Factor (Liebscher, 1895; De Wit, 1992) contributed to the understanding how to manage fertilizer input.

## 3. Agricultural sciences in the 20th century: capacity building in the public and private domain

Synergy between agricultural and plant sciences is a characteristic of progress made in the 20th century. The growing