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CENTENARY REVIEW

The changing context for agricultural science

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INTRODUCTION

There are many agricultures, and diverse components of each, so a journal of agricultural science must encompass a wide and ever-changing range of disciplines. The *Journal of Agricultural Science, Cambridge*, has done this in exemplary fashion from its very first issue one hundred years ago, which opened with Roland Biffen's (1905) paper on the use in wheat breeding of Mendel's recently rediscovered laws of inheritance. Another premonitory paper in that issue, on calcium cyanamide, was, as its author A. D. Hall (1905) put it: 'the first attempt on a commercial scale to bring atmospheric nitrogen into a state of combination, to manufacture, in fact, an artificial manure containing N derived from the air'.

Much of the progress in agriculture in the following century, during which the average yield of wheat in the UK has risen from 2 to 8 tonnes per hectare, has been due to the synergistic interactions between these two areas of research, and with other branches of agricultural science encompassed by this journal. The journal's history over the first 75 years was surveyed by Bell (1980), and illustrates well the continuing shifts in disciplinary emphasis and perspectives as agriculture has evolved. In recent years this evolution has been even more apparent among the books reviewed than in the papers published.

THE CURRENT RESEARCH SCENE

After several decades of expansion, public sector funding of agricultural research in the more developed countries as a whole is declining and is now less than that in the rapidly growing private sector (Pardey & Beintema 2001), reflecting the impact of genetic engineering and intellectual property rights. Research for further agricultural intensification and higher yields is also under siege in the face of greater public concerns for environmental maintenance, the conservation of genetic diversity, food and water quality, animal rights etc. Agricultural research policy is now viewed by many as an instrument of social policy (Alston *et al.* 2001). This trend is less manifest, so far, in the less developed countries where most of the future growth in population will occur, and where many (about 800 million) people are still chronically underfed.

Throughout most of history the food needs of increasing human populations have been met mainly by extension of the area under cultivation, but since 1960 this area has remained stable at about 1·4 billion hectares, while the average yield of cereals – the major source of human nutrition – has doubled for the world as a whole, increasing in step with world population (Evans 1998), and must continue to do so if further land clearing is to be avoided.

THE KEY ROLE OF SYNERGISTIC INTERACTIONS

Average cereal yields are the integrated end product of many processes being researched by reductionist scientists at various levels. For such research to be effectively used in agriculture, there must be continuing and effective interactions between researchers at the various levels of complexity. So journals like the *Journal of Agricultural Science, Cambridge*, which encompass research at various levels of analysis, can play an important role in the future evolution of agriculture. Breadth of disciplinary coverage is also important because of the synergistic interactions between advances in different disciplines, mostly recognized *post hoc*.

Consider the growth of the wheat grain, based on photosynthesis by the leaves and the subsequent transport of sugars to the developing ear. In Volume III (1909) of the *Journal of Agricultural Science*, Brenchley & Hall wrote: 'It is well known that the grain of wheat is built up out of the materials which have previously been elaborated by the plant … and stored in stems, roots and leaves until the formation of the seed begins … when the manufacture of fresh materials has almost ceased and the chief process going forward is the migration of accumulated

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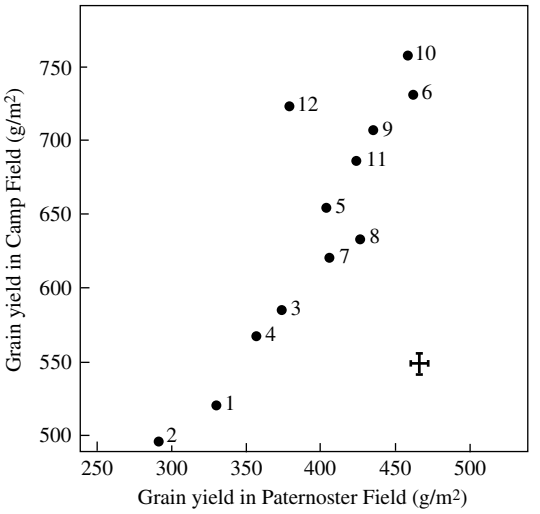


Fig. 1. Yields of varieties in Camp Field plotted against those in Paternoster Field. The numbers refer to those alongside the variety names in Table 1. ✢, S.E. of a value. Reproduced from Austin *et al.* (1980).

material from the stem and leaves to the grain'. But as nitrogenous fertilizers began to be used more widely, enhancing leaf growth and delaying leaf senescence, crop photosynthesis was prolonged and yield enhanced. Experiments with $^{14}CO_2$ by Helen Archbold (1945) revealed the increasing importance of post-anthesis photosynthesis by the upper leaves. But to capture these potential gains in yield potential required improved protection, nutrition and supplementary irrigation. The yield potential of modern cultivars is much higher, and pre-anthesis reserves now contribute only 5–10% of grain weight (Evans 1993). Moreover, as nitrogenous fertilizer manufacture became more efficient in terms of energy use, and therefore relatively cheaper, it was applied in heavier or more frequent dressings, necessitating the breeding of cultivars with shorter, stronger stems more resistant to lodging, thereby freeing assimilates for additional floral development and grain growth, as indicated by the slope of -1 for the relation between grain yield and straw weight in collections of English winter wheat varieties with vintages ranging from 1830 to 1986 (Austin *et al.* 1980, 1989). When the grain yields of these 12 varieties on a soil of high fertility are plotted against those at low fertility, there is a distinct upward curvature at the higher level of soil fertility (Austin *et al.* 1980, Fig. 1) indicative of a synergistic interaction between plant breeding and agronomy.

The genetic yield potential of a variety has been defined as the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting, and with pests, diseases, weeds, lodging and other stresses effectively controlled (Evans 1993), to which several glosses have been added by Evans & Fischer (1999). This definition recognizes the important role of plant breeding not only for genetic yield potential but also to maintain and improve the crop's resistances to pests, diseases and environmental stresses as well as to improve agronomy and crop protection. These latter activities fall under the rubric of 'maintenance research' in some agricultural research systems, such as the CGIAR, in contrast to 'basic', 'fundamental', 'productivity' or whatever research to raise the yield potential. But both must flourish if the steady rise in grain yields over the last 45 years is to continue. Their mutual interdependence needs to be recognized, as well as the folly of supporting one without the other. I suspect it is the interaction between them, the interdependence of their advances, which offers the most important scope.

In one of the most comprehensive long-term studies, for wheat in the Yaqui Valley of Mexico over a period of 22 years (1968/1990), Bell *et al.* (1995) found that wheat breeding accounted for 28% of overall farm yield progress compared with 48% for the increased use of nitrogenous fertilizer, but the breeding work included a substantial proportion of improved disease resistance, while the agronomic advances were far more than just increased N fertilizer application.

However, there is a strong positive relation among CIMMYT wheat varieties, IRRI rices and Pioneer maize hybrids between the number of land races in the genetic backgrounds of their varieties/hybrids and their relative yield potential (Evans & Fischer 1999), highlighting the value of conserving genetic resources for continuing crop improvement. Clearly G, E and $G \times E$ are all important to further progress in crop yields and, given the many interactions, both 'basic' and 'maintenance' research – species beloved of bureaucrats – require continuing support.

I emphasize such synergisms not only because they have characterized agricultural revolutions in the past but also because they make the point that in agricultural science overall progress, e.g. in crop yield, may be greater than the aggregate of individual disciplinary advances. There is an important role, therefore, for journals such as this, which publish papers across several levels of analysis and assist the dialogue between them. We need scientists who see agriculture as complex, but also see it whole. Walton (1999) has written that 'varietal innovation is a neglected aspect of British agricultural history' to which I would add 'especially its interplay with advances in agronomy and crop protection', as well as with the changing market demands which he has explored.

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THE WORLD FOOD SITUATION

In the more developed countries of the world population growth is, by and large, slow, crop yields high, arable land about 0·5 hectares per capita, and food production per capita more than adequate. By contrast, in many of the less developed countries (LDCs), population growth is still quite rapid, crop yields in many situations low, arable land less than 0·2 ha per person on average, and food production often inadequate, to the extent that about 800 million people are still chronically under-nourished. The world population is currently expected to increase by about 50% before it peaks, with nearly all of that increase in the less developed countries. Yet only about one third of the world's agricultural research expenditure is focused on their problems (Pardey & Beintema 2001), which are often quite different from those of the more developed countries. Moreover, whereas the projected increase in atmospheric CO_2 and global warming may enhance food production to some extent in the temperate developed countries, it is likely to reduce both arable area and yield per crop in many less developed ones. So if the yields of their cereal and other crops are to increase at least in parallel with their populations, and preferably much faster, they will need all the help they can get from agricultural scientists in the more developed countries, as well as those in international research systems and the international agricultural research centres. Rosegrant *et al.* (2001) estimate that the demand for cereals will increase by 1·3% per year until at least 2020, i.e. by as much as the increase from 1974 to 1997, with 52% of the increase being in Asia (27% in China, 12% in India).

Continuing agricultural research in the more developed countries could lead to greater surpluses available for export to the LDCs, often at highly competitive prices given the extensive subsidies supporting their production. These subsidies amounted to $US 327 billion in AD 2000, i.e. 1·3% of GDP for the OECD countries (IMF 2002), i.e. a thousand times more than the *annual* expenditure by the CGIAR on its 18 International Agricultural Research Centres, and ten times more than the total cost of world agricultural research. Moreover, while such subsidies encourage the DC farmer, they may discourage LDC farmers who often have to pay far more for their fertilizers and other inputs than do their more developed competitors. This, in spite of the admission in the same IMF document that: 'A coherent approach to development and trade calls for trade policies that create market opportunities for developing countries, and for development policies that enable them to respond to these opportunities'.

ETHICAL ISSUES

Bertolt Brecht once aphorized: 'Grub first, then ethics'. So a discussion of ethical issues in agricultural research may be seen as out of place in a journal of agricultural science, partly because agricultural scientists are prone to believe they are already on high moral ground for increasing world food availability, a belief which Dundon (2003) argues does not grant 'immunity from ethical scrutiny' 'because profound human values may be impacted by the choice of means of production'. In my book 'Feeding the Ten Billion' (Evans 1998), I included a brief discussion of 'Dilemmas for agriculturists, young and old' which has attracted discussion by several reviewers, not only for the socio-economic issues raised above, but also for scientific aspects, such as the interplay between publicly and privately funded research on genetic engineering in relation to intellectual property rights, payments and safety issues.

In their 'Issues' article on 'Patenting Agriculture', Barton & Berger (2001) discuss many aspects of the current drive to patent agricultural biotechnologies, particularly in relation to their impact on the opportunities for the less developed countries LDCs to make use of them to enhance the yield and nutritional qualities of their major food crops. They conclude that 'The patent system, designed to foster innovation, may be slowing it for some of these applications, e.g. in finding a way through the patent thicket surrounding "Golden Rice". But they also explore, constructively, ways in which the LDCs and the International Agricultural Research Centres could collaborate with the biotech industry to enable food production to keep up with population growth in the LDCs. Ethical issues are an important component in the mutual accommodation to avoid what has been referred to as a "scientific apartheid" excluding many LDCs from recent scientific advances' (Serageldin 2001).

Dalrymple (2003) began a recent review with the statement that 'Scientific knowledge in its pure form is a classic public good', a statement with which most of us would like to agree, while wondering how true it still is. I suspect that not only should we now be debating these issues more actively as they bear on our research, but also that the general public wishes us to do so. In 2003 the editor of the journal '*Plant Physiology*' instituted a series of papers on 'Agricultural Ethics' which has already exposed and considered a range of complex and significant issues in relation to the genetic engineering of plants and animals.

Philosophers are now beginning to discuss ethical aspects of agricultural research (e.g. Thompson 2003) and one of them (Dundon 2003) has stated his purpose as being 'to help all agriculturalists, but especially researchers, feel comfortable using ethics in handling the multiple and often conflicting demands that sectors of the public press on agriculture … It is not a work that can be left, as one wag put it, to the best ethicists money can buy'.

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Quite clearly, future agricultural scientists will be called on not merely to enhance agricultural production, but also to consider more explicitly the ethical as well as the environmental consequences of their research.

My first paper in *Journal of Agricultural Science*, on flowering in grasses, was published almost 50 years ago, another (with colleagues) on yield potential in British wheats 25 years ago, and with this, my last, I wish the journal a fertile future.

REFERENCES

Alston, J. M., Pardey, P. G. & Taylor, M. E. (2001). Changing contexts for agricultural research and development. In *Agricultural Science Policy: Changing Global Agendas* (Eds J. M. Alston, P. G. Pardey & M. E. Taylor), pp. 3–12. Baltimore, MD: Johns Hopkins University Press.

Archbold, H. K. (1945). Some factors concerned in the process of starch storage in the barley grain. *Nature* (*London*) **156**, 70–73.

Austin, R. B., Bingham, J., Blackwell, R. D., Evans, L. T., Ford, M. A., Morgan, C. L. & Taylor, M. (1980). Genetic improvements in winter wheat yields since 1900 and associated physiological changes. *Journal of Agricultural Science, Cambridge* **94**, 675–689.

Austin, R. B., Ford, M. A. & Morgan, C. L. (1989). Genetic improvement in the yield of winter wheat: a further evaluation. *Journal of Agricultural Science, Cambridge* **112**, 295–301.

Barton, J. H. & Berger, P. (2001). Patenting agriculture. *Issues in Science and Technology* **17**, 43–50.

Bell, G. D. H. (1980). The Journal of Agricultural Science 1905–1980. *Journal of Agricultural Science, Cambridge* **94**, 1–30.

Bell, M. A., Fischer, R. A., Byerlee, D. & Sayre, K. (1995). Genetic and agronomic contributions to yield gains: a case study for wheat. *Field Crops Research* **44**, 55–65.

Biffen, R. H. (1905). Mendel's Laws of Inheritance and Wheat Breeding. *Journal of Agricultural Science, Cambridge* **1**, 4–48.

Brenchley, W. E. & Hall, A. D. (1909). The development of the grain of wheat. *Journal of Agricultural Science, Cambridge* **3**, 195–217.

Dalrymple, D. (2003). Scientific knowledge as a global public good: contributions to innovation and the economy. In *The Role of Scientific and Technical Data and Information in the Public Domain* (Eds J. M. Esanu & P. F. Uhlir), pp. 35–51. Washington, DC: National Academies Press.

Dundon, S. J. (2003). Agricultural ethics and multifunctionality are unavoidable. *Plant Physiology* **133**, 427–437.

Evans, L. T. (1993). *Crop Evolution, Adaptation and Yield*. Cambridge: Cambridge University Press.

Evans, L. T. (1998). *Feeding the Ten Billion. Plants and Population Growth*. Cambridge: Cambridge University Press.

Evans, L. T. & Fischer, R. A. (1999). Yield potential: its definition, measurement and significance. *Crop Science* **39**, 1544–1551.

Hall, A. D. (1905). Calcium cyanamide. *Journal of Agricultural Science, Cambridge* **1**, 146–148.

International Monetary Fund (2002). *Improving Market Access: Toward Greater Coherence Between Trade and Aid*. IMF Brief, 1–10.

Pardey, P. G. & Beintema, N. M. (2001). *Slow Magic: Agricultural R&D a Century After Mendel*, pp. 1–30. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W., Paisner, M. S., Meijer, S. & Witcover, J. (2001). *2020 Global Food Outlook. Trends Alternatives and Choices*, pp. 1–18. Washington, DC: IFPRI.

Serageldin, I. (2001). Changing agendas for agricultural research. In *Agricultural Science Policy: Changing Global Agendas* (Eds J. M. Alston, P. G. Pardey & M. J. Taylor), pp. 13–20.

Thompson, P. B. (2003). Value judgements and risk comparisons. The case of genetically engineered crops. *Plant Physiology* **132**, 10–16.

Walton, J. R. (1999). Varietal innovation and the competitiveness of the British cereals sector, 1760–1930. *The Agricultural History Review* **47**, 29–57.

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