Field Crops Research 222 (2018) 121–142

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Loomis Review

Issues for cropping and agricultural science in the next 20 years

R.A. Fischer[a,*], D.J. Connor[b]

[a] CSIRO Agriculture and Food, PO Box 1700, Canberra City, ACT 2601, Australia
[b] Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Victoria 3010, Australia

ARTICLE INFO

Keywords:
Crop-environment interactions
Crop productivity
Farm yield
Food security
Global challenge
Potential yield
Resource-use efficiency
Sustainability
Research agenda
Yield gap

ABSTRACT

This position paper honours agricultural scientist and colleague, Professor Bob Loomis, by discussing the urgent global challenge of food security and the related impacts on the environment facing agricultural science and society in the next critical 20 years. It uses the concepts of potential and actual (farm) crop yields and the yield gap between them to assess current and future opportunities for food supply to satisfy increasing demand. The cropping world is seen in two parts. The first part predominantly comprises low-input farming with very large yield gaps and a faster growing demand that can only be met with increasing imports. For these regions, a well-established strategy is outlined for crop intensification through yield-gap closure that is essential for reducing rural malnutrition and poverty, and curtailing the likelihood of high food prices. For success, it must be complemented with strategies to remove the serious institutional and infrastructural barriers faced by farmers. The second part has more or less intensified, and yield gaps are generally small to moderate: it will fairly comfortably meet the demand from population growth. For these regions, some further yield gap closure is still possible but more importantly greater potential yields are required although the chances of accelerating this are discussed and seen to be limited. For all regions, sustainable intensification of cropping, predominantly on existing arable lands, is the best way forward. Combining sustainability with intensification is not a contradiction and is, in fact, essential; sustainability requires the efficient use of all inputs in cropping, and husbandry of the soil and agricultural biodiversity needed to continue to raise productivity. Off-farm environmental impacts are inevitable, but not insurmountable, hurdles. All aspects of sustainability require boosted RD&E and sound rural policies. Greater management skills for farmers and all others involved in crop production are also essential. Contestation based on biophysical aspects of food production and its impacts can be resolved through effective research and development with farmers, while that based on Northern cultural and normative views must not be allowed to obscure the goal of affordable food for all, and reward for farmers comparable with the rest of their societies.

Abbreviations: ACIAR, Australian Centre for International Agricultural Research; CA, conservation agriculture; CAP, common agricultural policy; C3 and C4, two pathways of photosynthesis; EU, European Union; EUE, energy-use efficiency; FACE, Free-air CO_2 enrichment; FY, farm yield; GHG, greenhouse gases; IWM, integrated weed management; GE, genetic engineering; GMO, genetically modified organism; NUE, nitrogen-use efficiency; NUEf, nitrogen-use efficiency of applied fertilizer; PUE, phosphorus-use efficiency; PUEf, phosphorus-use efficiency of applied fertilizer; PY, potential crop yield without water, nutrient or biotic stress; PY_w, potential crop yield under water shortage; RD&E, research, development and extension; SA, South Asia; SI, sustainable intensification; SIMLESA, Sustainable Intensification of Maize-Legume Cropping Systems for Eastern and Southern Africa; SOC, soil organic carbon; SSA, Sub-Saharan Africa; TE, transpiration efficiency; WUE, water-use efficiency; WANA, West Asia North Africa

* Corresponding author at: CSIRO Agriculture and Food, PO Box 1700, Canberra City, ACT 2601, Australia.
E-mail address: tony.fischer@csiro.au (R.A. Fischer).

https://doi.org/10.1016/j.fcr.2018.03.008
Received 7 March 2018; Accepted 8 March 2018
0378-4290/

Dedication

Professor Robert (Bob) S. Loomis (11 October 1928–27 March 2015), Professor of Agronomy[1] at the University of California, Davis, was a crop scientist famous for the breadth and depth of his interests. These ranged from plant tissue culture and basic metabolism, through crop canopies, growth and yield, to cropping and farming systems of North America and the lessons of farming history. Thus he became truly an agricultural scientist, thanks partly to strong links to the mid-west (see Loomis, 1984), where he grew up, and to his wife's home farm in Iowa, and partly to the agricultural ambiance of the Department of Agronomy and Range Science at UC Davis. He combined his broad interest in agricultural systems with a deep understanding of the basic science, the physics and chemistry behind the plant, crop and farm level phenomena (his first degree was actually in physics). He used these skills, along with his pioneering efforts in mathematical and simulation modelling, to quantify underlying relationships driving outputs at higher levels. All this can be seen in his early crop modelling papers (e.g. Loomis and Williams, 1969; Loomis, 1971; Loomis, 1985), his comprehensive review of agricultural productivity (Loomis, 1971) and in the book *Crop Ecology* (Loomis and Connor, 1992; Connor et al., 2011). Our review attempts to honour Bob Loomis's memory by adopting an equally broad view of the science of agriculture, but with our choice of issues and conclusions.

1. Introduction

Over the last 60 years or so, agricultural scientists, along with innovative farmers, small and large, have built, by intensification of inputs and capital per unit land area, very productive modern agricultural systems in many parts of the world (Spiertz, 2014). Farmers have adopted and modified new technologies such that crop productivity has advanced spectacularly, with a notable exception being the limited yield progress in Sub-Saharan Africa (SSA), and rainfed parts of South Asia (SA) and West Asia-North Africa (WANA). Problems, some serious, have inevitably arisen as intensification proceeds (see Section 6). In most cases, however, these problems of modernization are being overcome by newer technologies that increase resource-use efficiencies and reduce off-site impacts of agriculture. The important point is that these technologies seek solutions that can maintain the required productivity of agriculture. The cycle should continue so that sustainability, in its broadest sense, is reinforced by this ongoing process of sustainable intensification (SI). Nowhere has there been a need or serious desire, except amongst a privileged few, never full-time farmers, to return to the traditional farming practices left behind.

World population and per capita incomes, and hence food demand, will continue to increase, albeit at a slowing rate, until 2050 and beyond; seemingly only faster economic development and better education of women can humanely slow population growth. Agricultural science remains central to future food supply and to economic development in poorer nations, although alone it is obviously insufficient for the huge task ahead. It must attend to the on-farm technological aspects of SI of cropping in SSA and lagging areas of SA and WANA, by applying and further modifying, techniques and technologies that have been gradually refined in many other countries since the beginning of the second half of the 20th Century. At the same time there is a serious emerging challenge to agricultural science in developed countries where previously substantial yield gains are slowing, while further yield increase is needed to feed huge national populations and/or provide the exports of staple grains that support the food-deficit regions of the world. Crop productivity in developed countries is approaching a threshold that will need a modified paradigm for success at a time when scientific discoveries appear to be advancing with greater rapidity, yet government support for agricultural research, development and extension (RD&E) is declining and the sustainability of modern agriculture is being increasingly challenged by society.

Initially this review will update recent progress in crop yields, guided by the structure and arguments developed at greater length in Fischer et al. (2014). Space forces us to focus on global food production and affordability, primary amongst the various issues currently surrounding the food security debate (including also access, nutrition, health), and we will introduce a novel regional framing of the global agricultural challenge. This will be followed by a discussion of yield prospects across selected global agricultures of today, exploring in particular the future of the intensification paradigm that has been the basis of past progress in global food security. Inevitably attention must be given also to the sustainability of the intensification of input use that this implies. We will present ideas for the direction of future research and development to meet goals when starting from both a low and an already high yield base. We finish with reference to a new wave of contestation that contrasts with what will be an increasingly more complex science-based paradigm for global food supply. The latter forms the crux of our conclusion, in which we see continuing sustainable intensification of the world's cropping systems, involving even more technology and greater management skills, as not only possible but also essential.

2. Update on cropping demand and supply prospects

2.1. Global perspective

World grain production increased by 227% between 1961 and 2014 (Fig. 1) comprising +161% for yield and a much smaller increase (31%) in crop area, with more than half of the latter coming from increased intensity of cropping on existing arable lands. As a result per capita food availability has improved notably for a population that has risen 141%, and real food prices have fallen overall (Fig. 1).

Looking ahead to 2050, Fischer et al. (2014) concluded that a minimum target linear yield increase of 1.1% p.a. for staple crops (relative to 2010 yields)[2] was needed to hold prices down. Since then, world population projections (UN, 2017) have increased slightly to a predicted median of 9.8 billion for 2050 (31% above the 7.5 billion of 2017, a current rate of increase 1.09% p.a.) but there appears to be lower-than-anticipated expansion in the area of biofuel crops. Thus the 1.1% p.a. conclusion above remains reasonably valid, as does the desirability of lifting that rate to 1.2 or even 1.3% p.a. for greater security. Other estimates tend to opt for even higher yield growth rates (e.g. Nelson et al., 2010) if prices are to be held down, while recent economic equilibrium models deliver such a diversity of projected real prices to 2050 (von Lampe et al., 2014) as to reveal the great

[1] Agronomy is the science and technology of producing crops. Here, where breeding and agronomy appear in the same sentence, agronomy means crop management.

[2] This projection accepts the inevitability of an increase in net arable area of 0.25% p.a., or 140 Mha between 2010 and 2050.