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Evolution not revolution of farming systems will best feed and green the world

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ABSTRACT

The challenge to properly feed a world population of 9.2 billion by 2050, that must be achieved on essentially currently cropped area, requires that food production be increased by 70%. This large increase can only be achieved by combinations of greater crop yields and more intensive cropping adapted to local conditions and availability of inputs. Farming systems are dynamic and continuously adapt to changing ecological, environmental and social conditions, while achieving greater production and resource-use efficiency by application of science and technology. This article argues that the solution to feed and green the world in 2050 is to support this evolution more strongly by providing farmers with necessary information, inputs, and recognition. There is no revolutionary alternative. Proposals to transform agriculture to low-input and organic systems would, because of low productivity, exacerbate the challenge if applied in small part, and ensure failure if applied more widely. The challenge is, however, great. Irrigation, necessary to increase cropping intensity in many areas cannot be extended much more widely than at present, and it is uncertain if the current rate of crop yield increase can be maintained. Society needs greater recognition of the food-supply problem and must increase funding and support for agricultural research while it attends to issues of food waste and overconsumption that can make valuable reductions to food demand from agriculture.

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1. Introduction

The challenge facing global food supply during the next four decades to 2050, when the world population is expected to stabilize, is well known in scientific circles, and now in political and social circles also. A large (70%) increase in food production including 1000 Mt grain and 200 Mt meat, will be required to adequately feed a then population of 9.2 billion compared with the present 7 billion (Bruinsma, 2009). The population of currently developed countries is expected to fall slightly, so the global increase of population and food demand will essentially occur in developing countries, where 1 billion are already underfed. Any further contribution of crop production to biomass or biofuel energy and industrial chemicals will add to world crop demand. There are related issues of inequality, waste, diet and population control, but the major issue is which farming systems can provide the greater production required and save most land for nature and its other values and uses.

This article will argue that the solution is found in research and development to assist farmers to improve current farming practice, largely on existing agricultural land. These modern agricultural systems ("integrated agriculture") combine biological cycles with efficient use of external inputs to increase production through greater yield by continuously improving crop cultivars and agronomic technology. The unavoidable challenge for mankind, and for farmers in particular, is to do this in a way that protects the productive potential of agricultural land (the natural resource base) and minimizes impact on natural systems, *i.e.* "to feed and green the world". Proposals for transformation to agricultural systems of lower yield cannot contribute to greater production.

The challenge is not equally distributed throughout the world. The most vulnerable areas are in Sub-Saharan Africa (SSA) and parts of South Asia (SA) and Latin America (LA) where population is growing fastest, yields are low, and infrastructure, funds and services to provide and apply currently available technology are lacking.

2. Carrying capacity of land

Each human requires nutrition of plant, or from there, animal origin to support life, work, and leisure. The Standard Nutritional

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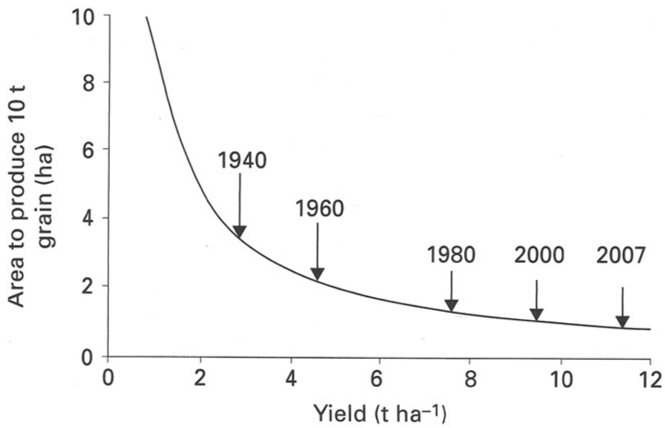

Fig. 1. Area of land required for production of 10 t grain as a function of yield per hectare. The arrows identify progression of US three-year mean maize yield, during the period 1940–2007 (Connor et al., 2011).

Unit (SNU), equivalent to annual agricultural production of 500 kg grain, is a way to measure food demand and carrying capacity of agricultural systems (Connor et al., 2011). This amount of production provides for inevitable losses in storage, seed for the next harvest, diversion of some production to fruits and vegetables, and grain to provide or complement animal diets. The importance of this number is not its absolute value, some would argue it could be smaller in some or all cases, but in its ability to provide an unambiguous link between productivity and carrying capacity of land. Thus, annual food production for 100 humans is 50 t grain equivalent that could be obtained on 50 ha at 1 t/ha but on only 5 ha at 10 t/ha. Importantly, the relationship between area required to feed a given population and yield is hyperbolic rather than linear.

The significance of this yield-area-production relationship to feeding an increasing population, and sparing land for nature (Waggoner, 1994), is seen clearly in Fig. 1 where it is related to the progression of maize yield in USA over the period 1940–2007. By increasing yield, less land is required to support a given population. On the other hand, if yield is allowed to decrease then proportionately much more land must be brought into production. So, are both options available? Greater productivity and more land?

3. Greater yield is the key to greater production

Of a total global land area of 13,000 Mha, arable land and permanent crops occupy 12% (1562 Mha) while permanent meadows and pastures occupy 26% (3406 Mha). Remaining land is forest, 3952 Mha (30%), or is unsuitable for agriculture, 4093 Mha (32%) (Nachtergaele et al., 2012). At present, most land suitable for cropping is in use, 596 Mha in developed and 966 Mha in developing countries. Total field crop production is currently about 2850 Mt, comprising 2100 Mt cereals, 140 Mt roots and tubers, 194 Mt sugar crops, 48 Mt pulses and 361 Mt oilseeds. A 70% increase would raise crop production requirement by almost 2000 Mt to 4850 Mt. Without greater yields, or further intensification of production (more crops per year), the additional land area required would be 1100 Mha.

Analysis that combines suitability of remaining land for cropping and competition for other uses, however, concludes that expansion of cropping land to 2050 will be small. An estimate of net increase is 120 Mha that is essentially restricted to developing countries, and mostly in SSA (64 Mha) and LA (52 Mha) (Nachtergaele et al., 2012). Intensification will increase annual harvested area, taking "effective" land increase to 160 Mha. On a world basis, 15% of arable land is irrigated and currently produces 42% of all crop production. That is expected to increase little by 2050 (16 and 43%, respectively). Corresponding figures for developing countries reveal a similar relative small expansion in irrigated area (19–20%) but with a static contribution to production (47%). Irrigation is seen, however, to be a relatively more important contributor to production in developing rather than developed countries.

Given that anticipated expansion of cropping area to 2050 is small, amounting to 10% when intensification is included, the target of 70% greater production required to feed a population of 9.2 billion by 2050 can only be met with a substantial increase in yield. Evolving systems must be more productive than existing ones to meet that challenge. To be prudent, we propose seeking "proof of concept" with at least proportional increases during the intervening period, *e.g.* 50% increase by 2025. If during the period to 2050, a greater proportion of cropland is devoted to biofuel and other non-food crops, then even greater yield of food crops will be required to meet global demand.

Area devoted to biofuel crops in 2009 was small (*ca* 36–41 Mha) (Fischer, 2009; Liska and Perrin, 2011) while predictions of future expansion are difficult because they depend largely on future political decisions and relative prices for food and energy. UNEP (2009) report projections of 60–80 Mha, or even 166 Mha, by 2020, which are equivalent to 4%–11% of the current stock of arable land. Meanwhile political decisions already in place continue expansion of food crops for biofuel, *e.g.* sugarcane and maize for ethanol in Brazil and USA, respectively, and soybean and oil palm for biodiesel in Argentina and Indonesia. Decision makers do not appear to understand the enormous impact that biofuel production will have on an already precarious situation of food security. A simple concept such as SNU can help here. When grain is used to produce ethanol, the amount needed to feed a person well for one year will produce just 200 l (500 kg at 0.4 l/kg), equivalent to 140 l gasoline (Connor and Mínguez, 2006), sufficient to fill the tank of a modern family car on two or three occasions. Proposals and current actions to solve the impact of biofuel on food security by switching to non-food crops (*e.g.* Jatropha) are misguided because they too require land, water, and nutrients that could be used for food production. Crop residues (cellulose) offer the best potential for fuel, but only to the extent that removal from cropped fields does not impair soil structure or fertility beyond what can be redeemed by management and fertilizers. Summaries of recent field studies show that soil organic matter is consistently lost when crop residues are removed at high rates but there is large variability in results and continued, long-term studies are needed to quantify changes associated with harvest of crop residues (Karlen et al., 2012).

4. Limits to crop yield

Globally, average yields of major crops have increased steadily during the past 50 yr due to a combination of plant breeding and improved agronomic management. Results for major staple crops, presented in Fig. 2, show linear increases that other studies (Duvick and Cassman, 1999) reveal have been sustained at continuously increasing investment in plant breeding. As yield has increased, relative (%) gain has decreased, causing concern in some circles, especially as evidence accumulates of possible plateauing of yield in some high yielding systems (Grassini et al., 2011). That should be expected, however, as yield increases towards an inescapable attainable maximum, determined, at each site, by interaction of genotype with environment. Just what that attainable yield is and how it controls currently existing

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