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Problems of Agricultural Economics

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SELECTED PROBLEMS OF WORLD AGRICULTURE

Summary

World agriculture faces a serious challenge: how to guarantee a relevant quantitative and health standard of food provision to a growing, and probably increasingly more affluent population, at the same time, reducing – or at least not increasing – the pressure on the environment and climate change. Competition for land, freshwater, energy and mineral resources, necessary to produce potassium and phosphorus fertilisers, will be tougher, as well.

However, there are some strategies to meet these challenges. Coordinated and consistent actions are necessary, both on the side of demand (changes in diet and consumption patterns, and reduction in food losses) and supply in agri-food markets. In particular, it is necessary to close the existing yield gaps, improve the efficiency in the use of all resources, invest in research and agricultural implementations, and reduce losses across the entire food chains. Individual actions should be taken simultaneously and on a global scale, which, in itself, poses a serious problem.

This instantly brings to mind the climate negotiations: almost everyone agrees that multilateral agreements would maximise the overall well-being, but the temptation to "get a free ride" prevails among many countries, as priorities continue to have short-term objectives and effects.

Key words: world agriculture, climate change, safe operating space, food security, agri-food demand, price elasticity, CGE and PE models, diet change, sustainable intensification

Introduction

The modern world, alive with multifaceted and multilevel interconnections, faces many challenges which in order to be met require harmonised decisions, actions, management, regulations and coordination, setting up relevant institutions and innovative funding at a global level that have to start already today. Not claiming to present an exhaustive set of these challenges, it should be, nonetheless, pointed out that the demographic pressure, a change in diet and consumption patterns and the whole complex of problems linked to climate change, energy use and emission of greenhouse gasses and, on the other hand, still fragile economic growth, continually growing public debt, clear deflation pressure, widening income and wealth gap, disappointment with globalisation and a certain fragmentation of the world trade, and return of geopolitics and Realpolitik are not the best setting for agriculture and the food sector.

Agriculture, in turn, has to meet the increased demand for its products, but understood in a much broader sense than the traditional one, because the sector evolves towards bioeconomy, i.e. it integrates with the biotechnology, energy, mineral extraction and pharmaceutical sectors (Swinnen J., Riera O. 2013; Zilberman D. 2013). This should be done under a sustainable process – not harming the natural environment, biodiversity and provision of public goods, not deepening the climate change, but counteracting poverty and attending to the security and welfare of the consumers. Facing depletion of free land resources qualifying for agricultural use, the second Green Revolution will be probably required which will be based, mainly, on advanced molecular and theoretical biology supported by bioinformatics and mathematical modelling, namely in general by genomics and biotechnology. Thus, it will be necessary to make relevant financial, public and private inputs in agricultural research and implementations, but also to introduce regulations to properly internalise new types of externalities.

This paper is a review study, which is primarily aimed at identification of the selected problems, which the world agriculture will have to tackle in the coming decades, and at outline of possibilities of, at least, its mitigation. The first part presents general challenges for the agricultural sector, then the paper characterises determinants of agri-food and other types of demand. The further part of the article introduces the issue of supply generated by agriculture and reviews the strategic options of meeting the challenges.

Analysis placement

Table 1 compiles selected properties of world agriculture at the turn of the past and present decade of the 21st century. The Table shows, e.g., that this agriculture exhibits different types of imbalances. It is safe to assume that in the future these can strengthen along with population growth, competition for renewable and non-renewable resources will get tougher, and climate change and environmental degradation will progress. These global problems require a response also at the global level, i.e. an adequately constructed, implemented, financed, monitored and corrected policy. Figure 1 presents its outline in terms of a dynamic system.

Table 1

Selected properties of the world agriculture

Specification	Value
People in the world (billion)	7.0
Undernourished people (billion)	0.9
Obese and overweight people (billion)	1.5
People living on less than USD 0.25 per day (billion)	1.4
People living in dryland areas (billion)	2.0
People dependent on degrading land (billion)	1.5
People working in agriculture (billion)	2.6
Losses due to climate change (USD billion)	11.4
Utilised agricultural area (billion ha)	4.9
Area linked to animal rearing (billion ha)	3.7
Average annual growth in agricultural production in 1997-2007 (%)	2.2
Annual food losses (billion tonnes)	1.3

Source: Beddington J.: Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. CGAR, Denmark 2012.

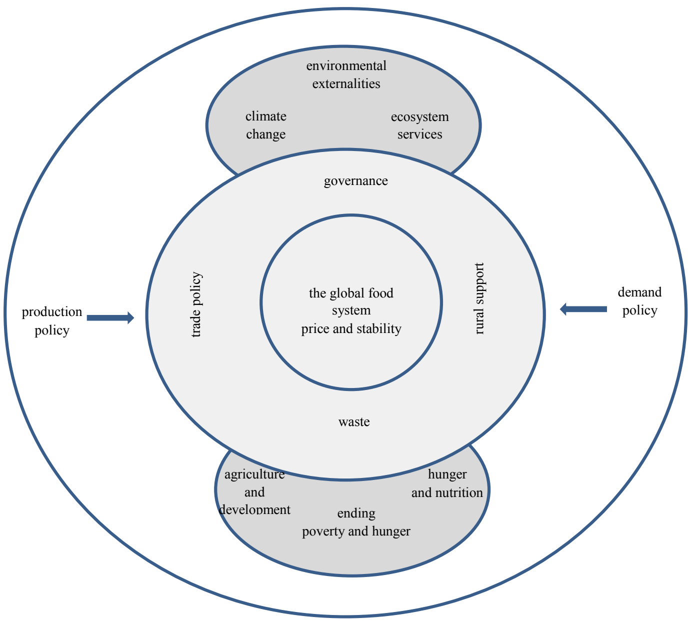

Fig. 1. The core of the global food policy

Source: own compilation on the basis of Godfray J.Ch.H., Garnett T.: Food security and sustainable intensification. Philosophical Transactions of the Royal Society B, no. 369, 2014.

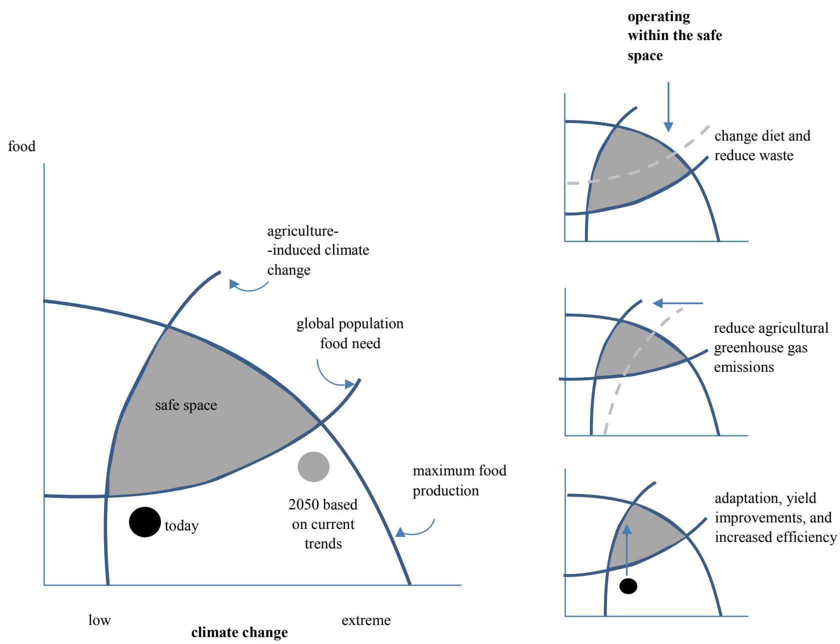

Fig. 2. The safe operating space in the interconnected food and climate systems

Source: own compilation on the basis of Beddington J.: Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. CGAR, Denmark 2012.

This refers to interconnected and dynamic elements set in the environment and subject to its impacts, but also exercising its return impacts on the environment. The key policy focus is the food objective, which can be accomplished by various paths or strategies. But action targeted at several areas simultaneously is the best, or even the necessary solution, but it is, in itself, extremely difficult to conceptualise or possibly optimise. Additionally, the differences in goals, priorities and values of the main global actors need to be considered. Therefore, consensus is a very complex evolutionary process, in which the periods of cooperation and global coordination will overlap with recurrence of protectionism and fragmentation of trade and the global economic system. Yet, it is worth to try to look for cooperation areas. In this context, the concept of creating the so-called safe operating space for the whole population seems very interesting. The left side of Figure 2 illustrates the essence of the safe operating space, while the right side shows partial strategies on how to enter or enlarge it. The dotted lines mark the baseline, while the continuous lines the targeted state achieved after carrying out the actions described by arrows pointed in respective directions. In highly stylised approach, the above space is a common area delimited by lines marking climate change, maximum food production capacities and food demand. At present, the world agriculture is outside of the safe space (dark dot on the left of Figure 2). To move ourselves into the safe space it is necessary to simultaneously change diet and reduce losses in agricultural raw materials and food, reduce the greenhouse gas (GHG) emissions, develop and implement technologies targeted at better efficiency and productivity of agriculture and the entire food chain. Progress in the area would automatically translate into reduction of the area expansion of agriculture to a minimum and limitation of the level of its unsustainable intensity. From the above it follows that the word "safe" means that it is theoretically possible to ensure adequate food security for the global community not exceeding the biophysical limits set by the natural environment of our planet. It needs to be added as a formality that the safe space can be enlarged along with a growth in the global capacity to generate increased supply of agri-food products (the maximum production curve in Figure 2 will move up).

Determinants of agri-food demand

Demand for one agri-food product follows from its price, price of other products enjoying the interest of a representative household, its income and structure of needs and preferences (Koester U., 2010). Whereas for aggregated demand, the rate of changes in the population figures, GDP and urbanisation are vital. Until recently, it was assumed that 9.2-9.3 billion people will live on our planet in the middle of this century. After that, population figures were to drop. Today, it is more and more often projected that the demographic pressure will continue until the end of the 21st century and the global population will reach even 12-13 billion. It was also universally assumed that the per capita income will grow, more than two-fold by 2050 against 2010 (von Lampe M. et al. 2014; Lotze-Campen H. et al. 2008). At present, it is not that certain anymore, but urbanisation will certainly progress. It is estimated that in 2007 as much as half of the population has already lived in cities and in 2025 the index will grow to ca. 56%, and in 2050 it can even exceed 75%. Thus, the cities will generate increasingly more GDP but also emit more and more harmful pollutants. Consequently, the concept of urban resilience, namely – in a nutshell – their sustainable growth and development, starts to gain in importance.

Past experiences show that, higher per capita income and inflow of rural residents to cities considerably change the diet structure and quantity of food intake. Figure 3 presents the main trends in the field.

In general, it is apparent that the consumption of cereals and vegetables fell, and the consumption of sugar, fat and animal products grew. On the whole, the quantity of consumed protein was fairly stable, but it was more and more often sourced from animal products. Fat consumption increased even at high per capita income, while polysaccharides were to an increasingly higher extent replaced with monosaccharides. Then, carbohydrate consumption dropped, on average, at relatively moderate per capita income (Beddington J. 2012; Godfray J.Ch.H. et al. 2010; Godfray J.Ch.H. et al. 2014; Smith P. 2013). These changes have serious health-related ramifications (they boost the percentage of overweight and obese people and diseases related thereto), they also influence the production technology and systems, and intensity of farming in the sector. The food industry also undergoes serious changes as deep processing is increasingly more important. As a result, there emerges a very dangerous combination: many world residents still suffer hunger but, simultaneously, the poorest are the most affected by the negative health effects of changes in eating habits. Regrettably, the economists are very much at odds as it comes to the assessment of the future agri-food demand. The above refers to both the general and partial equilibrium models, which are fraught, above all, by severe shortage of reliable estimations of price and income elasticities of demand[1].

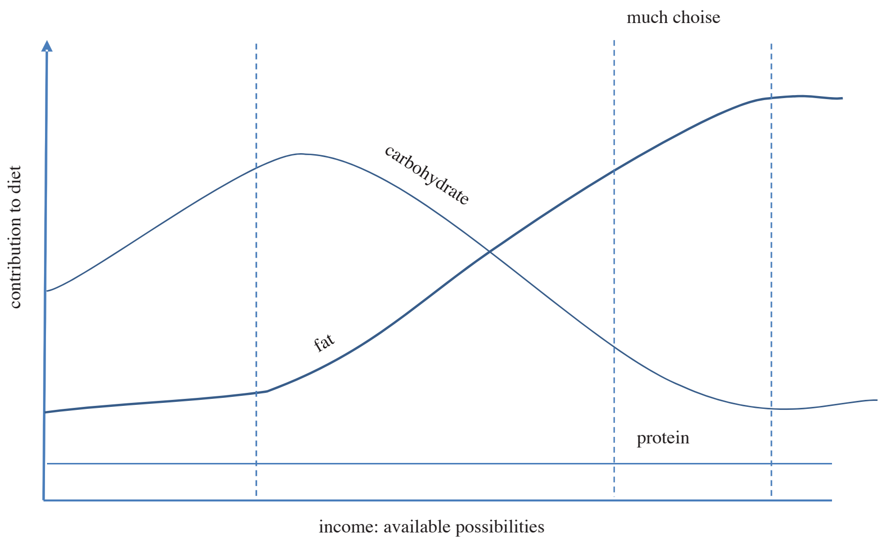

Fig. 3. Interconnections between diet and income

Source: own compilation on the basis of Beddington J.: Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. CGAR, Denmark 2012.

[1] However, it needs to be kept in mind that contemporary analyses of demand for and supply of agri-food products increasingly more often refer to the concept of sustainable diet. According to FAO this is a term which tries to integrate food security and safety, the issues of biodiversity, the environment and climate, fair trade, and even cultural heritage and culinary traditions (Kwasek M., Obiedzińska A. 2014). Such a broad concept will make modelling of demand for and supply of agri-food products even more difficult.

The future global agri-food demand can be modelled with the use of the computable general equilibrium (CGE) models and the partial equilibrium (PE) models. Problems linked thereto will be presented by reference to the comparative analysis of 6 CGE models and 4 PE models, conducted by H. Valin et al. (Valin H. et al. 2014). The research covered 13 world regions, and key plant and animal products, and the modelled years were: 2005 and 2050. Measures of the future demand were kcal per capita and day, and monetary units.

The PE models usually describe demand in rather simple terms, using the reduced functions; they have an unlimited degree of freedom but, in general, a rather narrow scope, mainly, of agricultural raw materials expressed in quantitative (physical) units, they use the consumer surplus in the form of caloric intake as an index measuring affluence of households[2]. Whereas the CGE models were derived from input-output accounts. The demand system is described therein under the utility concept. Restrictions of the models follow from the adopted demand function, since they focus on final consumption of goods, which are in general less numerous, but captured in detail across the entire food chain. Consumption is measured there in monetary units and affluence of a representative household is estimated with an equivalent or compensatory utility variance.

In standard approach the PE models express food demand per capita as follows:

$$D_{r,c,t} = Pop_{r,t}\left(\frac{Y_{r,t}}{Pop_{r,t}}\right)^{\eta_{r,c,t}} \prod_{c'}\left(P_{r,c',t}\right)^{\varepsilon_{r,c,c',t}} \qquad (1)$$

where:

$D_{r,c,t}$ – food demand for good c, in region r and year t,
Pop – population,
Y – total income,
P – vector of product prices,
η – income elasticity of demand for a given good,
ε – price elasticity of demand for a given good or mixed price elasticity of demand.

The population figures and changes in income are exogenous categories in the above specification, while prices are endogenous. At this point, precise consideration of the Engel's law, which states that income elasticity of demand drops when income of consumers increases, constitutes a considerable challenge.

[2] This definition of consumer surplus is greatly different from its understanding in the economy, which captures the consumer surplus as the additional benefit of a purchaser of a given good above the expenditure incurred on the purpose. Sometimes, the surplus has a nonstandard definition in the environmental economy.

Another demand estimation option in the PE models consists in expressing it in calories, which value constitutes a limitation in solving a given optimisation problem. Demand equation is, then, as follows:

$$D_{r,t} = Pop_{r,t} F\left(\frac{Y_{r,t}}{Pop_{r,t}}, t \right) = Pop_{r,t}\alpha(t)\left(\frac{Y_{r,t}}{Pop_{r,t}} \right)^{\beta(t)} \tag{2}$$

The $\alpha(t)$ and $\beta(t)$ parameters are estimated in the econometric procedure on the basis of panel data concerning the historical demand and income per capita. Demand for animal products (*LS*) in this approach has to be set separately, though. The proposal of FAO is often used here, which is illustrated by the following equation:

$$LS = G\left(\frac{Y_{r,t}}{Pop_{r,t}}, t \right) = \rho(t)\sqrt{\frac{Y_{r,t}}{Pop_{r,t}}} e^{-\frac{Y_{r,t}}{Pop_{r,t}}\sigma(t)} \tag{3}$$

The *p(t)* and $\delta(t)$ parameters are also estimated econometrically. The term $\rho(t)\sqrt{\frac{Y_{r,t}}{Pop_{r,t}}}$ grows in countries of low per capita income, but stagnates when the income is high. Whereas the term $e^{-\frac{Y_{r,t}}{Pop_{r,t}}\delta(t)}$, approximates zero for very high per capita income. It needs to be clearly emphasised that the second approach does not include prices of agricultural products; hence, it is not fit for analysis of supply and climate shocks, and bioenergy production.

The agri-food demand in the CGE models refers to the concept of utility and budget constraints category of households. At this point, there immediately appears a challenge, which consists in reflecting, as accurately as possible, an empirical fact in them, namely a growth in per capita income causes a drop in expenditure on food in the budgets of representative households. The Linear Expenditure System (LES) was the first solution that appeared and the utility function therein is as follows:

$$u_{r,t} = \prod_{c} \left(d_{r,c,t} - \gamma_{r,c,t} \right)^{\mu_{r,c,t}} \tag{4}$$

where:

- u – utility,
- d – per capita consumption,
- μ, γ – estimated parameters, the second one is defined as the minimum consumption level.

Maximising the *u* function against a given budget constraint, the following demand function is obtained:

$$d_{r,c,t} = \gamma_{r,c,t} + \frac{\mu_{r,c,t}}{P_{r,c,t}}\left[y_{r,t} - \sum_{c'} P_{r,c',t}\gamma_{r,c',t}\right]$$
$$\Downarrow \tag{5}$$
$$D_{r,c,t} = Pop_{r,t}\gamma_{r,c,t} + \frac{\mu_{r.c.t}}{P_{r,c,t}}\left[Y_{r,t} - Pop_{r,t}\sum_{c'} P_{r,c',t}\gamma_{r,c',t}\right]$$

where:
y – per capita expenditure on goods and services.

From the above it follows that demand is the sum of consumption minimum (γ) and the rest left from expenditure after its coverage (μ). The rest is defined as additional income. Unfortunately, LES sometimes is at odds with the empirical observations and is characterised by little possibility as it comes to operating the different price elasticities of demand. When γ is a fixed value, the system goes to Cobb-Douglas function.

Alternative solution is the use of a nested CES function, i.e. a combination of the following utility functions:

$$u_{r,i,t} = \left(\sum_j A_{r,i,j} \cdot d_{r,i,j,t}^{\rho i}\right) \tag{6}$$

where:
$u_{r,i,t}$ – utility linked to consumption of a certain group (set) of food products *i*,
$d_{r,i,j,t}$ – demand for product *j* in group *i*,
$A_{r,i,j}$ – function calibration parameters.

The price elasticity of demand is now defined by elasticity of substitution between food and non-food goods. Thus, preferences of consumers and diet changes are reflected along with a growth in income of representative households.

The agri-food demand can be modelled also with the use of the Constant Differences in Elasticity (CDE) of utility function. A practical procedure usually starts with definition of the intermediate utility function and the demand function is expressed by the next formula:

$$d_{r,c,t,} = \frac{\alpha_{r,c,t} b_{r,c,t} u_{r,t}^{e_{r,c,t} b_{r,c,t}} \left(\frac{P_{r,c,t}}{y_{r,t}} \right)^{b_{r,c,t}-1}}{\sum_{c'} \alpha_{r,c',t} b_{r,c',t} u_{r,t}^{e_{r,c',t} b_{r,c',t}} \left(\frac{P_{r,c',t}}{y_{r,t}} \right)^{b_{r,c't}}} \tag{7}$$

where:

b – substitution effects between price elasticity of a given good and mixed price elasticity,

e – a parameter reflecting the demand reactions to a change in income.

Although this approach gives a more realistic estimation of price elasticity of demand than LES, sometimes the income elasticities for the final year of modelling are close to the values from the starting year.

Other methods are definitely more rarely used in demand modelling. However, these still refer directly to the utility function, as it is the case for, e.g., rank number of the function and the Implicit Directly Additive Demand System (AIDADS) directly or indirectly converging with LES under set conditions. The second approach covers, above all, the translog function and its derivatives in the form of the Almost Ideal Demand System (AIDS) and in the functional form, encompassing the quadratic term in the part describing the per capita level of income. The latter enables to move smoothly to the third rank number of the utility function. Researchers still seek new approaches that would more accurately capture the evolution of the price and income elasticities of demand; hence, the changes in the behaviours of consumers, their preferences and diets for as wide spread of per capita income as possible. The more desired dynamic properties of the utility function are necessary to periodically recalibrate the CGE models if one wants to accurately forecast demand in a long term and, on the other hand, to correctly capture the increasingly more complex interconnections in the global supply chain of agri-food products and in chains of generating value added in them.

H. Valin et al. conducted a comparative analysis of the global agri-food demand projection for 2005-2050, using as a point of reference the results obtained by FAO (Alexandratos N., Bruinsma J. 2012). The overall conclusions are as follows:

1. In the intermediate scenario, which projects that in 2050 the world population will stand at ca. 9.2 billion and the average per capita income will double (from USD 6,700 to USD 16,000), the average – for all models – growth in agri-food demand is to total ca. 74%. To compare, the FAO estimate slightly

exceeded 54%. Also the spread of results given by Valin et al., included between 62% and 98%, exceeds the assessment of the creators of the FAO models. This discrepancy follows, primarily, from the fact that Valin et al. assumed that the level of per capita income in 2050 will be higher by 50%, mainly in China and India. It has to be added straight away that income effects of demand growth for some models were strengthened or reduced by price effects. The average result for plant products, amounting to ca. +69%, was once again higher than the one obtained by FAO (+50%), and the range of variation was between +55% and +97%. The case was the same for animal products (on average, +103% for 10 models and +76% for FAO), but the spread of estimation was far greater (between +61% and +242%).

2. In the second socio-economic scenario it was assumed that population in 2050 will amount to ca. 10.2 billion and the highest birth rate will be noted in Africa, India and Southeast Asia, but the global GDP will equal only ca. 2/3 of the level from the first scenario. The greatest regression of the product (GDP) and per capita income would take place in China (drop by 46%), India (-50%) and in Sub-Saharan Africa (-52%). In the group of developed countries (OECD and CIS), the average total consumption dropped by 14% against the first scenario, because the price and income elasticities of demand are lower there, but a decrease in the population figures in these countries will have an even greater impact on the situation. Whereas in developing countries, the demand for plant products can, on average, grow slightly, mainly because of continually growing population, but this will sporadically refer also to animal products which in this group of countries are characterised by higher income elasticities of demand. Estimates are very uncertain as regards the actual formation of consumption of the meat of non-ruminants in China and India, and dairy products in the latter country.
3. The reactions of agricultural production, prices of agricultural products, incomes of consumers and agri-food demand to climate change – expressed as the average for four scenarios, but, all in all, very close to the most pessimistic version (carbon dioxide concentration grows from 370 ppm to 540 ppm), turned out to be very surprising. Most of the models showed a significant price elasticity of demand. However, the problem consists in the fact that one should expect this from their construction. But then, food consumption – measured in kcal per capita and day – in response to the climate shock would drop from 1.6% to 2.9% for the average from ten compared models. Even in the models which are the most sensitive to this shock the drop is not higher than 6%.
4. Only three models had satisfactory solutions to reflect the impact of production of the second generation biofuels on agricultural production. The worst case scenario provides for a drop in kcal consumption per capita and day by 1.5% (33 kcal).

Dilemmas linked to supply of agricultural products

Supply of a single agricultural product is a function of its price, price of other products, prices of factors of production used in the production processes, state of technology, goals and behaviours of agricultural producers (Koester U. 2010). Whereas aggregated supply of agriculture on a national, regional and global scale is determined by availability of the factors of production, elasticity of their substitution, trajectories of land use, efficiency of photosynthesis, rate and character of changes in the total and partial productivity of involved resources and its price elasticity.

The global supply of agricultural products, additionally broken down by countries and their groups, geographical regions and forecasted for distant future years, is also modelled with the use of the CGE and the PE-class tools. In the latter, shallow and deep structure models are additionally distinguished. The selection between the CGE and the PE is difficult, but it is recommended to settle the case based on an empirical principle (Robinson S. et al. 2014). If agriculture is still an important sector of the national economy and its functioning has a considerable significance for further links of the value generation chain, the feedback existing between the food sector and the rest of the national economy can be better captured with the use of the CGE models, but different attempts are also undertaken to use deep the PE models for the purpose. Hence, it needs to be accepted that the latter better capture technological and production ties governing the functioning of agriculture.

Agricultural production technologies in the CGE models are described with the use of production function or cost function. In the former case, CES-type function is definitely more often used than the Cobb-Douglas function, which follows, e.g., from the fact that the CES-type function under specific conditions (unit elasticity of input substitution) turns into the C-D function. If the modeller decides to use the CES-type function, the procedure can begin with the following specification:

$$X = F(H,Z) \tag{8}$$

where:

H – acreage of land in ha,

X – set of a certain crop,

Z – complex resource of other factors of production (Robinson S. et al. 2014).

The Z argument reflects the fact of multilevel nesting of the CES function. This covers a complex structure of at least two inputs/factors of production. In the CGE models used in practice inputs include: land, labour (additionally broken down by unqualified and qualified), capital, energy, natural resources, materials in general (including used in crop production), fodder. Only this circumstance points to the source of a high differentiation of the results of supply modelling.

The production function, given as equation 8, is the 1st degree homogenous to H and Z, i.e. it reflects the fixed economies of scale. To get to the yield per one hectare, it can be transformed as follows:

$$y = \frac{X}{H} = \frac{\partial F}{\partial Z}\left(\frac{Z}{H}\right) + \frac{\partial F}{\partial H} \tag{9}$$

The simplest PE models explicitly use land acreage and yields, but they disregard other factors of production. However, the case is different for the CGE models, in which yields depend on the relative significance (share) of individual factors of production and change in their productivity. This leads to the issue of elasticity of substitution of factors of production. For the aforementioned CES-type function with two factors, a set of a defined crop can be written in another way:

$$X = a\left[\delta Z^{-\rho} + (1-\delta)H^{-\rho}\right]^{-1/\rho} \tag{10}$$

where:

a,δ,p – parameters, δ stands for share of inputs other than land.

Thus, elasticity of substitution equals:

$$\sigma = \frac{1}{1+\rho} \tag{11}$$

Having the CES-type production function and assuming that the land factor will be a fixed value the variable cost function linked thereto can be thus transformed to ultimately obtain the elasticity of supply of agricultural production against price (ε):

$$\varepsilon = \frac{\hat{X}}{\hat{P}} = \sigma\left[\frac{a^{\rho}}{1-\delta}\left(\frac{X}{H}\right)^{-\rho} - 1\right] = \sigma\left[\frac{\delta}{1-\delta}\left(\frac{H}{Z}\right)^{\rho}\right] = \sigma\left[\frac{\delta}{1-\delta}\left(\frac{H}{Z}\right)^{\frac{1-\sigma}{\sigma}}\right] \tag{12}$$

Next, if the problem is simplified and we prepared the initial data for the modelling, so as $Z = H = 1$, δ and (1-δ) will stand for the shares of these factors in the value of agricultural production. Then, elasticity of supply is reduced to the following:

$$\varepsilon = \left(\frac{\delta}{1-\delta}\right)\sigma \tag{13}$$

Elasticity of supply can be a fixed value in the Cobb-Douglas production function. But, if the share of land (fixed factor) in the production value grows, the elasticity drops. In turn, in the CES-type function elasticity of supply reacts to the value of *H/Z* quotient. The latter usually decreases over time. When elasticity of substitution is lower than one, elasticity of supply will fall, as far as the value of *H/Z* ratio will also drop. This is a dominant assumption in the CGE models. This means that the elasticity of supply should decrease when the economy still develops. It needs to be added that elasticity of supply, in the two considered production functions, responds also to the share of the fixed factor (land) in total returns (profitability, profits/income) on the sum of factors of production or in value added. When the share grows, supply is increasingly more inelastic. Moreover, in the CES-type function the elasticity of supply decreases along with deterioration in the elasticity of substitution. This is a typical situation in developing agriculture and economy, i.e. for such conditions the elasticity of supply is lower than one. In more advanced analyses, at this point it would be required to consider additionally the fact that elasticity of supply should be estimated against "net" prices, i.e. the difference between the price of an agricultural product and the cost of indirect inputs (materials) per one product unit[3]. This adjustment can be, however, overlooked for the agriculture of less developed countries where indirect inputs are still used to a limited extent.

In the simplest PE models the supply of agricultural production is presented explicitly in connection to the functions of land acreage, yields and prices of agricultural products and inputs (P_j). This is described by the following three-term formula:

$$\begin{aligned} X &= yH, \\ y &= \alpha \prod\nolimits_j P_j^{\eta_j}, \\ H &= \beta \prod\nolimits_j P_j^{\mu_j}, \end{aligned} \tag{14}$$

The above specification assumes that plant yields grow when prices of respective crops grow, and they drop when prices of inputs increase (e.g. mineral fertilisers)[4]. The acreage of land under a given crop is also a function of prod-

[3] This definition of "net" price is greatly different from its understanding in the economy and accounting, in which it is captured as the difference between the price paid by the purchaser (gross price) and the due VAT.

[4] It needs to be noted that this is a normal reaction of supply to the growing price of agricultural product. However, in practice abnormal reaction sometimes happens, which is also known as reverse reaction, i.e. farmers react with increased supply to price drops (Koester W. 2010).

uct prices. The general elasticity of supply against prices is here a sum of parameters η and μ for their level given each time. It is a fixed value, lower than one (inelastic supply as well) for the entire modelling period. This is a very strict assumption. But it may change in the deep PE models, when it follows from the simulation. Then, supply is captured implicitly as a result of solving a given optimisation problem. Inclusion of technical progress is a complex issue of modelling supply of agricultural production. In the shallow PE models this is reflected in changes in yielding trends. The exogenous technical progress is also thus revealed in deep-type models, but it can also have an endogenous component in them, when one wants to consider the input prices or land availability. In the CGE models with the CES-type production function the above progress can be expressed as follows:

$$X = a\left[\delta(a_z Z)^{-\rho} + (1-\delta)\ (a_H H)^{-\rho}\right]^{-1/\rho} \tag{15}$$

where:
a – "neutral" total factor productivity (TFP),
a_Z – technical progress expressed in factors of production other than land,
a_H – technical progress expressed in the land factor.

Although improvement of all types of productivity leads to an increase in yields, at the same time, it can change returns on individual factors of production which, as a result, impacts elasticity of supply of agricultural production and prices of products. This, additionally, overlaps with the differentiated rate of changes in productivity of land and other factors of production, among which modellers strongly emphasise labour productivity (S. Robinson et al. even use the term of efficient elasticity of supply). Moreover, the following are also important in the implemented CGE models: formation of TFP in agriculture and other sectors of the national economy, inter-sectoral mobility of factors of production (it reflects, e.g., sensitivity of supply of agricultural production to the changes in agri-food demand, which is captured by the dynamic function of Constant Elasticity of Transformation (CET)) and relations between evolution of land supply over time and production supply.

Empirical research usually has very interesting results, i.e. growth in TFP in agriculture of highly developed countries exceeds its rate in the industry and services (Kets W., Lejour A. 2003). But then, in developing countries TFP in agriculture increased faster than in the industry. Whereas the unresolved interconnections for medium-developed countries are a problem (Martin W., Mitra D. 2001). In this context, it should be noted that in the financial sector changes in TFP were very low, sometimes there was even a drop in the index. This is a very unfavourable phenomenon if we consider financialisation progressing across the world, which stands for excessive growth of the financial sector against the GDP, that was is one of the major sources of the last crisis.

S. Robinson et al. held extensive comparative research of six CGE models and four PE models as regards the global simulation of supply of agricultural production in 2010-2050 (Robinson S. et al. 2014). The analysis covered a total of 15 plant and animal products. The general conclusion is obvious: the results are highly varied and without agreement of the basic assumptions of modelling this situation will continue. But if agreed, the PE models do not have to give way to the solutions prepared under the CGE convention.

The aforementioned research team has conducted a detailed analysis on the MAGNET CGE model simulating the effects of three scenarios:

1. Continuation of the former demographic trends and GDP growth rate.
2. No differences in the TFP index across sectors.
3. Technical progress expressed only in the land factor.

Upon relevant calculations it turned out that:

- For scenario 1 – total product prices could reduce in 2050 by 20%, for scenario 2 – only by ca. 2%, but for scenario 3 – they could grow by nearly 60%. Paradoxically, this shows how important for price processes in agriculture is the technical progress expressed in labour, which in highly developed countries is, on average, higher than in services.
- Total supply of the analysed products in 2050 would be clearly higher than in 2010. The growth rates would amount, respectively, to 54% (scenario 1), 50% (scenario 2) and 46% (scenario 3). Growth dynamics would be, of course, higher if the price and income elasticities of demand were higher, but in reality these are low and they will probably stay low also in the future. It should be noted that the estimated growth in supply of agricultural production clearly lags behind estimates of the global demand obtained by Valin et al.

At this point, it should be added that the above-presented high differentiation of modelling results is a serious problem in itself, as it can even challenge the practical applicability of such works. Consequently, the International Association of Agricultural Economists (IAAE) invited the representatives of the leading centres dealing with modelling to try and harmonise the fundamental assumptions taken therein. This resulted in a special edition of the "Agricultural Economics", a journal of the IAAE, which was published in 2014. The team's works continue and the next publication is to be presented in 2016.

Ch. Müller and R. Robertson analysed the probable impact of the climate change on yields of 23 selected plants across continents (Müller Ch., Robertson R.D. 2014). At this, they decided to take the most pessimistic scenario, termed as RCP 8.5 (the representative concentration pathway with a radiative forcing 8.5 W/m^2). According to it, CO_2 concentration in 2050 will probably amount to 540 ppm and in 2100 it can even reach 935 ppm. It was assumed that the above scenario will be included into to general circulation models (GCM), i.e. climate models: HadGEM2-ES and IPSL-CMSA-LR. The second modelling dimension consisted in two global crop growth models: the Decision Support System for Agrotechnology Transfer (DSSAT) and the Lund-Potsdam-Jena managed Land (LPJmL). The former is based on the model of crop area, while the latter is an ecosystem model. From the above it follows that the Müller and Robertson are primarily focused on the character of modelling biophysical interconnections. Table 2 presents their basic results for 2050.

Table 2

Probable global drops in yields (%) of selected five crops in 2050 caused by climate change

Crop	Climate models			
	HadGEM2-ES		PSL-CMSA-LR	
	Crop growth models:			
	DSSAT	LPJmL	DSSAT	LPJmL
Wheat	-17.7	-11.5	-21.0	-12.9
Maize	-37.6	-9.9	33.9	-14.2
Rice	-15.7	-18.2	-16.4	-16.1
Soybeans	-16.8	-20.4	-13.0	-29.8
Groundnuts	-20.9	-24.3	-18.4	-21.2

Note: model indications are given in the text.

Source: own compilation on the basis of Müller Ch., Robertson R.D.: Projecting future crop productivity for global economic modeling. Agricultural Economics, vol. 45, no. 1, 2014.

As per the Table, yield drops were severe. Modelling, especially in the spatial dimension, is, however, biased by major uncertainty because data are often aggregated across steep gradients caused by going from low to high impacts of climate change. In fact, the regression in yielding does not have to be so significant, because Müller and Robertson overlooked the possibility of the so-called CO_2 fertilisation, i.e. a positive response of some crops – especially characterised by C4 photosynthesis – to higher CO_2 concentrations in the air and climate change adaptations feasible in agriculture.

The most fundamental issue, in the considerations on the conditions of supply of agri-food products, is the possibility to increase the efficiency of photosynthesis. This inevitably directs our attention at genetic engineering, today, supported by advanced mathematic modelling techniques and calculation capacities of computers growing by leaps and bounds. But, if the very modelling is concerned, the multiscale concept offers the greatest possibilities. In short, it consists in simultaneous analysis of the molecular (molecular modelling), cellular (using ordinary and partial differential equations), systemic (agent-based modelling) and ecosystem (finite-element method modelling) levels.

The growing interest in increasing the efficiency of photosynthesis stems from universally known reasons, namely demographic pressure and diet changes accompanying enrichment of the society and urbanisation, but also gradual depletion of the yielding potential of currently cultivated crops and decreasing financial inputs for agricultural research and implementations. It is also important that more efficient photosynthesis means better assimilation of carbon dioxide which may slow down climate change slightly. It is enough to say that the concentration of the GHG before the industrial revolution was at 280 ppm and now it is higher than 400 ppm, but by the end of the current century it can even exceed 560 ppm (Long P.S., Marshall-Colon A., Guang-Zhu 2015). Such a scenario means that the average temperature of our planet can grow by 4-5°C. Until recently it was considered that the limit value for the world population is a growth of not more than 2°C (Leggevie C., Welzer H. 2012; Stern N. 2010).

The possibilities of improving the efficiency of photosynthesis will be presented mainly based on the article of S.P. Long et al. (Long et al. 2015). The team starts with a simple equation:

$$Y_P = Q \cdot \varepsilon_i \cdot \varepsilon_c \cdot \varepsilon_p ..... \qquad (16)$$

where:

- Y_p – potential yield per one land unit without stress-inducing factors,
- Q – total solar radiation emitted in the growing period per land unit,
- ε_i – efficiency of absorbed solar radiation by a plant,
- ε_c – rate of solar energy conversion into plant biomass,
- ε_p – part of biomass gathered in the form of usable yield, the so-called harvest index.

The first Green Revolution managed to double ε_p, which today stands at ca. 0.6 for wheat, rice and soybeans. But the efficiency, similar to ε_i and ε_c, currently approximates the upper limit. The low actual value of the parameter ε_c is a problem in particular. For plants classified as C3 photosynthesis, namely plants which in the dark phase (part of the Calvin-Benson cycle) temporarily create a three-carbon compound (3-Phosphoglyceric acid), ε_c is ca. 0.02 – i.e. ca. $^1/_5$ of the theoretical efficiency. Type C3 includes, e.g., wheat, rice, soybeans and sugar beets. In the case of the C4 photosynthesis (e.g. maize, millet, sorghum, sugar cane), in the Hatch-Slack cycle, there temporarily appears the four-carbon compound: oxaloacetic acid. These plants theoretically have the ε_c level equal to 0.13, but in general they have developed anatomic and physiological mechanisms enabling them to increase carbon dioxide concentration in their cells as compared to C3 plants. The latter, appear mainly in the temperate climate, while the C4-type plants – primarily in the tropical climate, but in Europe this type of photosynthesis is encountered in over 100 wild plants.

The problem with C3 plants consists also in the fact that, as a result of respiration, they can lose even 97% of water. Plants with C4 photosynthesis are more sparing in this respect, as they can close their stomata, hence they are better off in drought periods. A more complex is the impact of carbon dioxide concentration on assimilation, which also means on the efficiency of photosynthesis. The C4 plants have the so-called compensation point for the concentration near zero – then the amount of CO_2 created as a result of respiration and photorespiration equals the assimilated amount. For C3 plants this point ranges from 0.009% to 0.018% (atmospheric concentration is ca. 0.036%). At low concentrations of this gas, photosynthesis intensity for C4 plants is higher than for C3 plants. But at values close to optimum concentration the latter gain some advantage over the former. This fact is used for the so-called CO_2 fertilisation of plants in greenhouse cultivations. But how this fertilisation could look like for field crops it is not clear. It needs to be remembered that the CO_2 concentration above 1% is toxic for plants and inhibits photosynthesis. In practice the problem is much more complicated because photosynthesis depends also on the colour and intensity of the solar radiation, air temperature, oxygen concentration and water availability. This, however, does not affect the importance of general conclusion of Long et al., namely that there are numerous promising possibilities to extend the efficiency of photosynthesis. Comparison 1 shows that some of them are almost at the fingertips, others are a rather far-off perspective. It is also very important that this new cannon of necessary actions by Long et al. offers, at the same time, room for improvements in the use of water and mineral resources in fertilisers. The water issues are also strongly emphasised by, e.g., A.M. Chaudhry and E.B. Barbier (Chaudhry M.A., Barbier B.E. 2013).

Strategy to cope with the challenges

Assuming that, in the future, a global surplus in agri-food demand over supply of agri-food products is very likely, it is necessary to take up and, at the same time, implement actions aimed at:

- reducing losses across the entire food chain and adjusting to climate change as well as reducing GHG emissions in agriculture and counteracting soil and water degradation;
- enhancing productivity of agricultural land unit by implementing technical progress, the best practices, reasonable crop irrigation and possibly also area expansion, if sustainable;
- reducing demand by diet change, promoting healthy behaviours and minimising food losses and waste for households (Beddington J. 2012).

This is, undoubtedly, the most comprehensive, ambitious and difficult strategy. Figure 4 presents the key idea behind it.

Comparison 1

Possibilities of enhancing efficiency of photosynthesis for C3-type and C4-type plants

Manipulation instrument	Manipulation type	Efficiency growth (%)	Implementation perspective	Additional benefits
Making it possible to use the near infrared light	C Syn	10-30	L	improvement in C3 and even 10 times in C4
Accelerating heat release in the reaction centre	PSII Syn	30	S	synergies with other C4 changes
Transformation of C3 into C4 plant	Syn	30	L	better efficiency in water and nitrogen use
Adding cyanobacteria and microalgae genes to CO_2/HCO_3 pump	Syn	5-10	L	as above
Adding cyanobacteria genes to the CO_2 fixing system (carboxysome)	CSyn	60	L	as above
Adding pyrenoid (protein structure) of algae to the CO_2 concentration system	CSyn	60	L	as above
Replacing carboxylase enzyme (catalyses CO_2 fixing) with another one better adjusted to the current CO_2 concentrations	CSyn, B	15-30	L	as above
Synthetic bypass of photorespiration	Syn	15	S	as above
Optimising production of the interim products – ribulose-1,5-bisphosphate	Sys, B	60	S	general synergies; improved efficiency and use of near infrared light for C4 plants
Higher light interception level by lower leaves	B, Syn	15-60	S	synergies with instruments 1, 3-9, more efficient water use and higher albedo for C4 plants

Indications: CSyn – synthetic addition of a gene, Syn – synthetic genome manipulations, Sys – adding or reducing the number of genes, B – manipulations in cultivation works, L – long-term (10-30 years), M – medium-term (5-10 years), S – short-term (1-5 years).

Source: own compilation on the basis of Long P.S., Marshall-Colon A., Zhu G.H.: Meeting the global food demand of the future by engineering crop photosynthesis and yield potential. Cell, no. 161, 2015.

Another strategy, which is closely linked to the one above but, at the same time, of partial character, is the closure of the yield gap. The term is usually narrowed down to crop yields. In such case, it stands for the difference between their maximum and actually achieved level in the given geographical region (Beddington J. 2012; Godfray J.Ch.H. et al. 2010; Godfray J.Ch.H., Garnett T. 2014). There are, however, no obstacles to use the yield gap also for unit yields of animals. But the further discussion is limited to crop yields. It needs to be noted, though, that the maximum level of crop yields is in no way the same as the biological potential of a given crop. It is a paradox that in some regions of the world inputs in agriculture are used in excess, while in others the same inputs are deficient. The very fact of reducing this global imbalance as it comes to inputs would contribute to rationalisation of this phase of agricultural production. It would also be desirable to better match the inputs to the requirements of plants and animals, dose them more accurately, promote recycling, regulate water relations, improve a broadly-conceived management, including risk management. According to estimates by A.J. Foley et al., if it was possible to approximate 16 basic agricultural raw materials to 95% of their potential, it would be possible to increase their global production by 2.3 billion tonnes and thus supply $5x10^{15}$ kcal (Foley J.A. et al. 2011). The closure of the gap in 75% would increase plant biomass by 1.1 billion tonnes and energy by $2.8x10^{15}$ kcal.

Highly advanced research of the yield gap was conducted also by N.D. Mueller et al. (Mueller N.D. et al., 2012). The team analysed 17 plants covering ca. 76% of the global arable land. Modelling included the 1997-2003 period. It was stated that the climate, use of mineral fertilisers and irrigation of crops explain 60-80% of the observed global yield variation. At this point, the major issue is to establish a system, under which in some world regions the fertilisation level and area of irrigated land should increase, while in others the intensity of using these production factors should drop, because even now it shows unsustainability and inefficiency. Undoubtedly, precise agriculture, simplified cultivation systems, technical and biological progress and orientation at multi-functionality of the available space will support the process of achieving a new balance, without harming the environment. Organic fertilisers, soil potential and the applied management practices will also play a significant part. But Mueller et al. did not consider these factors, which does not change the very spectacular results of their modelling. Because it turned out that the closure of the yield gaps in 100% could increase the global production of the researched crops by 45-70%.

However, if it was possible to eliminate excessive use of mineral fertilisation, maize, wheat and rice crop yields could increase by ca. 30%. A positive impact of such reduction in NPK fertilisation on the environment is obvious. It needs to be added, nonetheless, that Eastern Europe, alongside Sub-Saharan Africa, have the largest yield gaps worldwide.

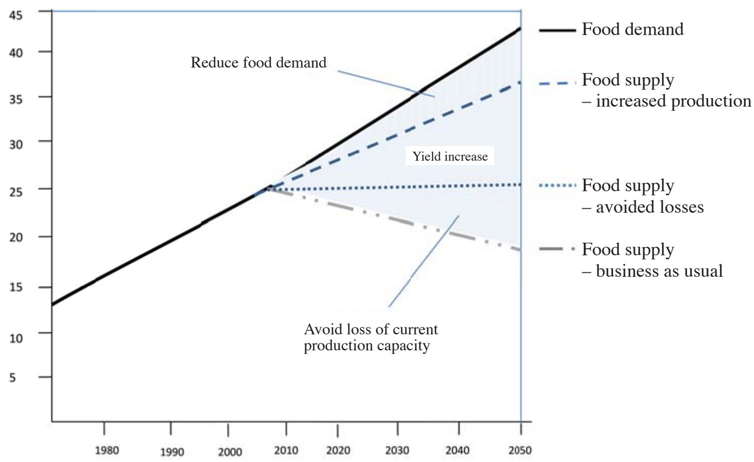

Fig. 4. Possibility to equalise food demand with its supply

Source: own compilation on the basis of Beddington J.: Achieving food security in the face of climate change. Final report from the Commission on Sustainable Agriculture and Climate Change. CGAR, Denmark 2012.

Reducing the land yield gaps will, to some extent, contribute also to their mitigation as regards the labour factor. As shown by D. Gollin et al., land productivity in non-agricultural sectors is even four times higher than in small holding agriculture (Gollin D. et al. 2012). As evident, the issue of the yield gap was here extended to highlight the ties between agriculture and the rest of the national economy, and possibilities of improvement in the total productivity and wealth, included in the reallocation of resources to the most efficient applications. The reallocation in the very agriculture would extend the economies of scale, which is not considered in modelling of the land yield gap. On the other hand, we have to eschew treating the narrowing down of yield gaps as simple improvement in the income of small holders and mitigation of rural poverty. The key to solving these problems is mainly in non-agricultural sectors. It needs to be remembered that in many African countries as much as half of all working people is employed in agriculture, and in Ethiopia and Burkina Faso the index is as high as 75%.

The closure of the yield gap is very tightly linked to the strategy of sustainable intensification. This means simply generation of a greater amount of agricultural production per land unit, at the same time, reducing the negative impacts of agricultural production for the environment, without the need to seize new areas for agricultural purposes (Franks R.J. 2014; Godfray J.Ch.H. et al. 2010, Godfray J.Ch.H., Garnett T. 2014). Figure 5 presents the major assumptions of the concept. The efficient *G* holding is situated on the production possibility frontier (PPF), which can move upwards as a result of technical progress and item *z* stands for technically inefficient farm. All units situated on the PPF can implement the strategy of sustainable intensification when it moves up and to the right. The inefficient *z* holding has several development trajectories to reach efficiency. For example, it can chose option *a*, i.e. it can increase yields at constant volume of provided ecosystem services. It can also try to improve yields and the volume of ecosystem services simultaneously (options *b* or *c*). Option *d* stands for improvement of environmental efficiency only (but is it sustainable intensification?). Whereas options *e* and *f* should be considered together as a case when formerly non-agricultural land is covered by cultivation. Such a combination would make sense and it would fall within the ambit of a broad understanding of sustainable intensification, if production growth coexisted with provision of additional ecosystem services. Practical importance of such a situation is clearly strongly limited, especially in countries of high population density. As evident from the above, options *b* and *c* are the most favoured.

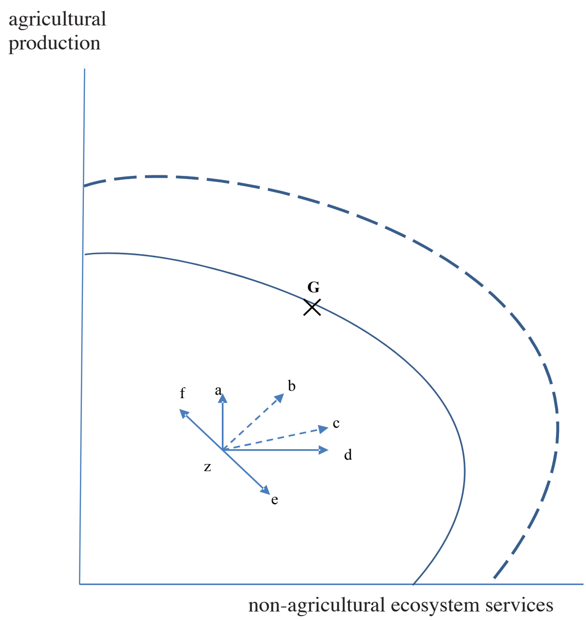

Fig. 5. The idea behind sustainable intensification

Source: own compilation on the basis of Franks R.J.: Sustainable intensification: A UK perspective Food Policy. No. 47, 2014.

In fact, the above strategy can be implemented under two options, i.e. "the land sparing model" – meaning that land allocation to individual applications complies with the principle of comparative advantage, and "the land sharing model". The latter refers to treating land as a resource, which is to be used simultaneously for provision of agricultural raw materials and ecosystem services. Of course, this option is very close to the EU concept of sustainable agriculture but it is much more demanding as it comes to its relevant translation into agri-environmental policy. Another challenge is spatial differentiation of the instruments of this policy and it requires to create a cohesive system of incentives for all stakeholders, including also governmental payments for provided agri-environmental services. The two options of sustainable intensification also assume that farmers behave in a rational manner, very similar to the strategy of the closure of the yield gap.

Sustainable intensification can be a component of a broader concept, i.e. the conservation agriculture (CA). Sustainable intensification as a part of the conservation agriculture covers three basic elements:

– minimising the impact on land through mechanical cultivation;
– greater quantity and better fixation of organic substances in soil;
– diversification of crops;

and four additional factors:

- use of well-adjusted varieties producing high yields;
- better supply of nutrients to plants (mainly by soil fertility);
- integrated management against pests;
- integrated management of plant diseases, weed infestation and efficient water management (Franks J. 2014; The Hague Conference... 2010).

It needs to be added straight away that the CA is a serious challenge for most of the farmers, because it is a knowledge-intensive system, which requires farmers to choose between combinations of practices and adjust them creatively to the local conditions (Kassam A. et al. 2011). But then, the concept should be an important tool helping to adapt to the climate change. This leads us straight to the final strategy – Climate-Smart Agriculture.

This is a type of agriculture which, at the same time, sustainably increases productivity, resilience (adaptation), reduces GHG emissions, guarantees the desired level of food security and makes a positive contribution to the achievement of overriding socio-economic goals (The Hague Conference... 2010).

This type of agriculture comprises the ten conditions:

1. All countries, but especially the developing ones must undergo a significant transformation in order to guarantee food security and adjust to climate change.
2. Effective practices of climate change adaptation and greenhouse gasses reduction in the agricultural sector are already in place.
3. It is necessary to adopt an ecosystem approach targeted at the entire biophysical space and coordinated joint actions for its protection.
4. Considerable investment is required in data collection and knowledge creation, in research on conservation and production of new animal breeds.
5. Smallholders require financial and institutional support.

6. Strengthening the institutional capacity in dissemination of the best practices regarding climate change adaptation and reduction in GHG emissions.
7. Greater consistency between agriculture, food security and climate change is necessary at the national, regional and global level.
8. Available financing, current and projected, is insufficient to meet food security and climate change challenges.
9. It is necessary to achieve synergy between public and private funds and implement authentic financial innovations.
10. Financing instruments and mechanisms are required under the so-called fast-tracks, for instance, to deal with sudden shocks well-adjusted to the local agriculture (The Hague Conference... 2010).

Conclusions

World agriculture faces a serious challenge: how to guarantee a relevant quantity and health standard of food to a growing, and probably increasingly more affluent population, at the same time, reducing – or at least not increasing – the pressure on the environment and climate change. Competition for land, freshwater, energy and mineral resources, necessary to produce potassium and phosphorus fertilisers, will be tougher, as well. There are, however, some strategies to meet the challenges. Coordinated and consistent actions are necessary, both on the side of demand (changes in diet and consumption patterns, and reduction in food losses) and supply in agri-food markets. In particular, it is necessary to close the existing yield gaps, improve the efficiency in the use of all resources, invest in research and agricultural implementations, and reduce losses across the entire food chains. Individual actions should be taken simultaneously and on a global scale, which, in itself, poses a serious problem. This instantly brings to mind the climate negotiations: almost everyone agrees that multilateral agreements would maximise the overall well-being, but the temptation to "get a free ride" prevails among many countries, as priorities continue to have short-term objectives and effects.

Predicting the future is always risky and uncertain. This fact seriously hinders, e.g., integrated economic-ecological-climate modelling which is very necessary in global agri-food policy-making. Because, undoubtedly choices concerning model specifications, namely their functional form and parameters, elasticity of demand and supply, the set of calibration data (and sometimes periodical re-calibration), approach to aggregation and optimisation methods generate serious differences in modelling results. Therefore, modellers need to cooperate closely and parameters have to be simulated to meet the challenges.

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WYBRANE PROBLEMY ROLNICTWA ŚWIATOWEGO

Abstrakt

Przed rolnictwem światowym stoi poważne wyzwanie, jak zapewnić rosnącej liczbie ludności, prawdopodobnie też przeciętnie bogacącej się, odpowiedni standard ilościowy i zdrowotny wyżywienia, obniżając – a przynajmniej nie zwiększając – presję na środowisko przyrodnicze i zmianę klimatu. Będzie rosła zatem konkurencja o zasoby ziemi, wody, surowców energetycznych i mineralnych niezbędnych do wytwarzania nawozów potasowych i fosforowych.

Istnieje jednak kilka strategii sprostania powyższym wyzwaniom. Potrzebne są skoordynowane i konsekwentne działania zarówno po stronie popytu (zmiany diety i wzorców konsumpcyjnych oraz redukcje strat, jak i podaży na rynkach rolno-żywnościowych. W szczególności trzeba starać się zamknąć istniejące obecnie luki produktywności, poprawić efektywność zastosowania wszystkich zasobów, inwestować w badania i wdrożenia rolnicze, zmniejszyć straty w całych łańcuchach żywnościowych. Pojedyncze działania powinno się podejmować przy tym równocześnie, i to na skalę globalną, co samo w sobie stwarza ogromny problem.

Od razu nasuwa się tu refleksja związana z negocjacjami klimatycznymi. Niemal wszyscy zgadzają się, że przyjmując wielostronne porozumienie, łączny dobrobyt uległby maksymalizacji. Jednak pokusa jazdy na gapę przeważa wśród wielu krajów, bo wciąż priorytety mają cele i efekty krótkookresowe oraz interesy narodowe.

Słowa kluczowe: rolnictwo światowe, zmiana klimatu, bezpieczna przestrzeń operacyjna, bezpieczeństwo żywnościowe, popyt rolno-żywnościowy, elastyczność cenowa, modele CGE i PE, zmiana diety, zrównoważona intensyfikacja

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