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Opinion paper

Food security as a function of Sustainable Intensification of Crop Production

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Abstract: The challenge to eradicate hunger and establish food security across all its four pillars (availability, accessibility, health and safety, and continuity) is ongoing. The actual situation in global food production leads most of the attention to improving accessibility and safety of food, particularly to vulnerable populations. However, in view of the growth in demand, which includes changes in preferences for example towards food of animal origin, availability and continuity will play larger roles in future. Food production needs to increase over the coming decades at challenging rates, while facing problems of degradation and reduced availability of natural resources for production such as soil and water, and facing increasing challenges from climate change. The actual trends in yield development suggest that a simple gradual improvement of production within the existing concepts will not provide a sustainable or feasible solution, and that more fundamental changes in the agricultural production paradigm are required to face these future challenges. The Sustainable Intensification represents such a change in paradigm in which high production levels are combined with sustainability. The concept of sustainable intensification, the rationale for it and its functional elements, represented by Conservation Agriculture, are presented in this paper.

Keywords: sustainable intensification; Conservation Agriculture; soil; no-till; food security; sustainable agriculture

1. Introduction

Food security exists when "all people have, all the time, physical, social and economic access to enough, innocuous and nutritive food for satisfying their daily energy needs and food preferences, in

order to have an active and healthy life". Food security has four main pillars [1], namely:

1. Physical availability of food
2. Economical and physical access to food
3. Appropriate and healthy use of food
4. Stability of these factors over time.

The term sustainable intensification has become popular in recent years and while its definition can vary, it can be considered in both a narrow and a broader sense. The narrow definition applies to the pursuit of the dual goals of higher yields (output) and productivity efficiency with fewer negative consequences on the environment while building resilience, natural capital and at the same time enhancing the flow of environmental services [2–4]. This combines increasing biological outputs, productivity efficiency, resilience, and ecosystem or environmental services through integrated production systems development and landscape management in rainfed and irrigated landscapes. A whole range of ecosystem services including; maintaining soil health, the quality of drinking water and air, control of erosion and other forms of land degradation, protection of water, nutrient and carbon cycling, pollination services and issues such as the protection of landscapes, habitats, biodiversity for ecosystem functioning and resilience, are considered [5,6].

In the broader context, sustainable intensification would encompass the above production and ecological dimensions, the biological products provided to and utilized by consumers and with minimum food wastage, as well as human and economic dimensions of socio-cultural aspirations, organizations and social equity, land tenure, employment and economic growth. It also implies improving the capacities of people (including farmers) and their informal and formal institutions to deliver and use inputs efficiently, manage systems, distribute and use outputs efficiently so as to avoid excessive wastage, and harness large-scale ecosystem services that benefit producers and consumers alike [2,3,7–9].

However sustainable intensification is defined, it is necessary to achieve increased yields and output in ways that do not harm the resource base and the environment, and even improve them. This review outlines the current situation of food security in the world and some of the challenges that can affect it. The review proposes an alternate paradigm of a "sustainable production intensification" to address the challenges. While the elements leading to this new paradigm, such as conservation agriculture, are not really new, the understanding that these concepts allow to achieve the production levels required without compromising the natural resource base, is fairly recent. This allowed the proclamation of sustainable intensification as a new paradigm, since it is achievable in practice. So far, high production levels were always combined with some sacrifices on sustainability, and so called "sustainable" approaches to agriculture sacrificed production levels. In this sense, sustainable agriculture was always a theoretic concept out of practical reach. The understanding of the impact of conservation agriculture has led to the term "sustainable intensification" which therefore can be considered a new paradigm.

2. The current situation of food security in the world

Nowadays, the world produces more than enough food for the entire population, although it is unevenly distributed. Around 30% of the food produced is even wasted, and a significant amount is fed to livestock and some used for producing biofuels. Nevertheless, with population growth and its increasing food demand, which includes the changes in food preferences towards products of animal

origin due to rising incomes and more people living in the urban areas, global production needs to increase by 60–70% over the next 30 years or so [7,10].

The current problem of hunger in the world is mainly due to lack of economic access to food caused by inadequate integration of developing world population into national economies which themselves are weak; however, there has been an improvement during the last three decades, as a result of the reduction in the extent of extreme poverty but also the absolute number of poor people remaining constant or decreasing slightly while the world population more than doubled.

There are also problems of undernourishment due to lack of balanced nutrients because of the inadequate use of food, but there is prevalence of obesity too in some countries at the same time. Both are signs of unhealthy and unbalanced nutrition which can be caused by problems of economic access, acquired preferences, lack of knowledge or culture.

Another challenge is the stability of food availability and accessibility. In the last decade, higher variability in availability and access has been noticed due to physical lack of food, and price volatility because of, for example, extreme climatic events [11,12].

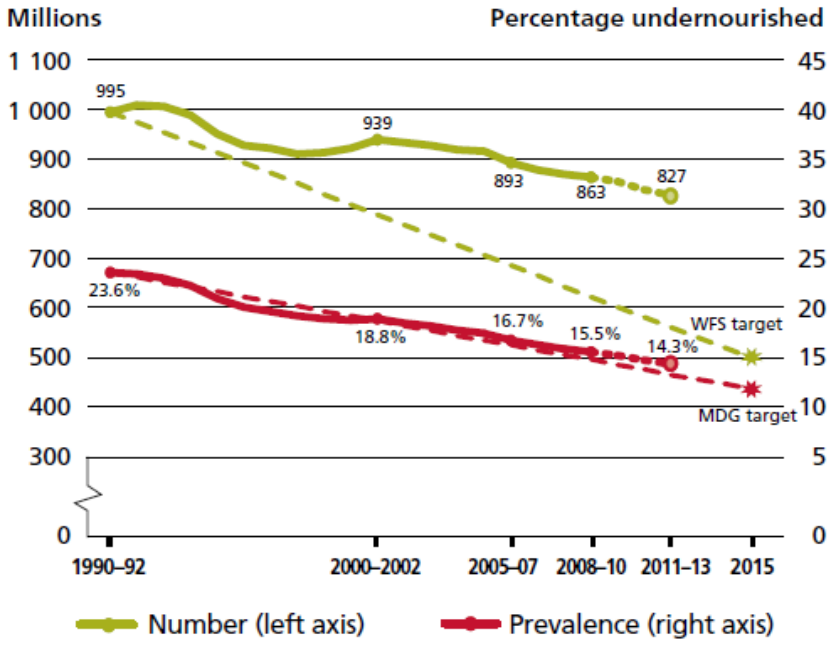

Figure 1. Trend in under nourished people in numbers and in prevalence from 1990 to 2015 (Data for 2011–13 in all graphics refer to provisional estimates; source FAO) [13].

The number of hungry people in the world has slightly decreased to 795 million in 2015. Considering the population increase, the first of the millennium goals, which was to reduce to half the percentage of hungry people between 1990 and 2015 was reached in Asia and Latin America, but missed by a little at global level [14] (Figure 1). Nevertheless, the goal of the Food World Summit, held in 1996, which suggested reducing the number of hungry people by 50% at 2015 was only reached in Latin America. It is also alarming that 98% of undernourished people live in developing countries and that hunger and poverty, particularly in rural areas, are closely linked [15], confirming the fact that the proximate cause of hunger is poverty. The goal to reduce and finally end hunger and poverty has been strengthened under the new agenda post 2015 with the Sustainable Development Goals, particularly SDG 1 and SDG 2 with the proposal to eradicate poverty and hunger until 2030 [16].

3. Food Security and some of its challenges

3.1. Prices

The first challenge is food prices. Since 2000 food prices generally tended to increase (Figure 2). This could be good news for farmers and food producers, but it makes it difficult for poor and vulnerable populations to access food. Besides, it causes problems to the economies of countries whose food security heavily depend on food imports. Also there has been a higher volatility of food prices in the last years. The soaring food price crisis of 2007/08 and 2011 directly affected the food security of 105 million and 44 million of people, respectively. This particular crisis has alerted many countries, particularly the net food importing countries, many of whom have since then declared the enhancement of national food production as a strategic objective for national security [17]. High price volatility seems to be a phenomenon which may not disappear soon because it results from the circumstances that characterize our world, namely [17,18]:

1. Incidences of droughts, floods, plagues and diseases as a consequence of higher climatic variability due to climate change and global warming respectively.
2. Strong and fast growing demands of emerging markets—many growing economies have large internal markets, and every change in them affects the world market.
3. Measures of trade and agricultural policies, many times as a response to food price volatility.
4. Energy price volatility, which has its direct effects on costs of food transportation and production, but also directly on food prices through the markets of biofuels.
5. Speculation with food prices on the stock market.

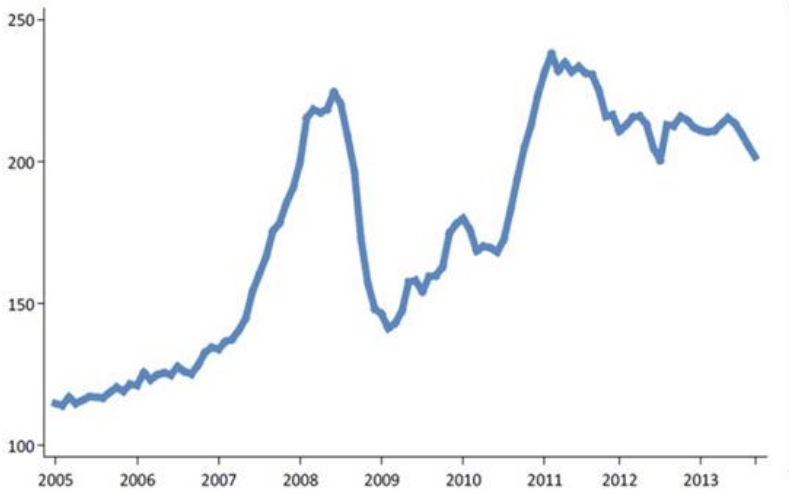

Figure 2. FAO price index for food from 2005–2013 [17].

This volatility of prices affects food security. It reduces the security of planning in the agricultural production, and this leads to a reduction of investments in the market. Agriculture can no longer be considered as a safe and calculable investment. However, there are also direct effects of price volatility on food security, like a sudden rise of food prices in the world market could endanger the food security of food importing countries with weak economies, while a drop in food prices could risk the subsistence of small producers that depend on the incomes from food sales for their survival [11,19].

3.2. Natural resources

Food production depends on natural resources, such as water and soils, which can be limited. Nowadays, agriculture uses 70% of the fresh water of the world, and, in many regions, water is a limiting factor for production. For doubling the production, agriculture should not use more water, since the limited resources have to be shared with other sectors with increasing demands, such as domestic water for the population. An increase of agricultural production has to result from the efficiency savings of water use, since many major watersheds in the world are already overexploited and in danger of running dry [20–22].

Another resource in danger is land. Globally, land resources are finite but agricultural lands are constantly lost due to other uses. Besides, lands used for agricultural production suffer from soil degradation, which is a global problem [3,23,24]. Soil degradation, which is a gradual process during which the soils lose their original production potential expresses itself at later stages in erosion and finally in desertification. It is actually affecting practically all soils under agricultural production and as a result many important cropping areas are facing decreased agro-ecological yield ceilings which do not allow further production increases despite application of additional inputs.

Soil degradation can be traced back in human history [23] until the very origins of sedentary agriculture. This suggests that the causes commonly listed as reasons for soil degradation, such as compaction by heavy machinery, overuse of fertilizers and chemicals or even climate change, might not be the original root cause of the problem. Instead it suggests that mechanical soil tillage, one of the first operations applied in agriculture, is the main cause of soil degradation. Soil tillage leads to a loss of soil biodiversity and organic matter, which results in the destruction of soil structure and porosity, reduction in the water and nutrient holding capacity and retention, increase in greenhouse gas emissions, and brings about problems due to droughts and flooding, soil losses due to erosion, and, finally, desertification [6,25,26].

3.3. Climatic change

Agricultural production is also, more recently, affected by climatic change, mainly by the increased frequency of extreme climatic events, which have their effect on food production. Once again, the fragile ecosystems, for example in the tropics, many times with vulnerable populations, are the most affected. Further, the impact of these extreme events is exacerbated by the ongoing soil degradation, which reduces the resilience of the soil and crops to respond to these extreme events. However, conventional tillage agriculture not only suffers from climate change, it also contributes to greenhouse gas emissions with the release of carbon dioxide, methane and nitrogen oxides. Carbon dioxide emissions are increased when soil organic matter is oxidised which occurs at a much faster rate when the soil is intensively disturbed by mechanical means, whether by the use of various types of ploughs, harrows, hoes or spades (Figure 3). Methane and nitrogen oxides come, for instance, from cattle production and flooded rice fields or compacted soils, i.e. conditions, were these greenhouse gases develop as a result of anaerobic fermentation processes. Agriculture also, indirectly, contributes to climatic change with the changes in the land use, as in the case of deforestation. Cutting down trees is not the only problem, but the agricultural use of lands that follows this deforestation with burning of biomass and the mechanical soil tillage, which leads to mineralization of soil organic matter, turning it into carbon dioxide emissions. Including land use change, agriculture contributes to 30% of the emissions causing the climate change [18,27,28].

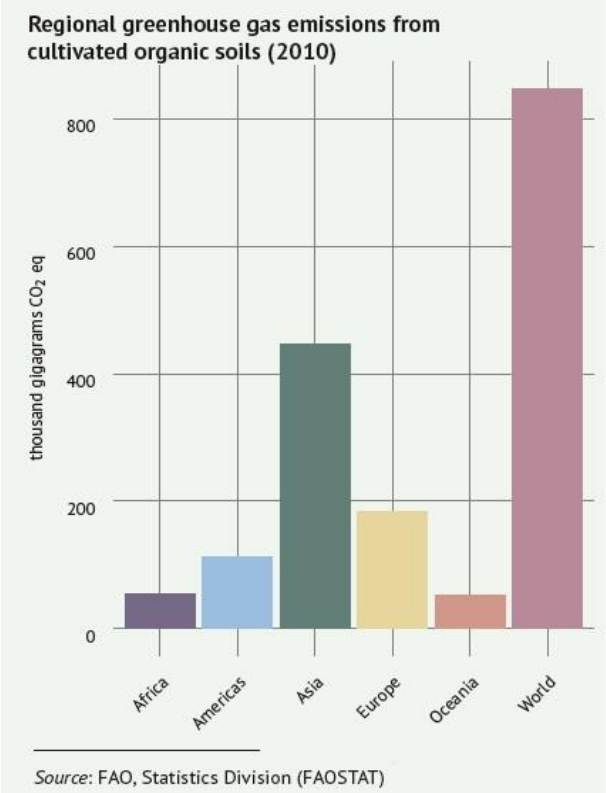

Figure 3. Carbon dioxide emissions from cultivated soils by continent [18].

3.4. Biofuel

Another factor that has affected food security during the last decade is the increasing market for biofuel. Production of biofuel crops increased up to 500% between 2001 and 2011 as a consequence of the increase in fuel prices and environmental considerations (Figure 4). In some cases, food commodities are destined directly to biofuel production. In other cases, biofuel is produced from non-food crops [29]. Nevertheless, all biofuel production competes with the food production for resources such as water, soil, workers, and technology. This way, biofuels can reduce food availability and access to food due to price increase. In both cases, food security is affected. As a response to climate change and sustainable land use biofuels also provide a questionable contribution: the carbon which is burned in biofuels for energetic purposes cannot be used for improving soil health, structure and for increasing the soil carbon pool [30,31].

3.5. Food preferences

With the increase of income level, there is a change of food preferences towards products of animal origin, like meat and dairy products. This phenomenon mainly appears in growing and diversifying economies, such as China and India. With the increase of population in these countries, the increase in income, urbanization tendencies and change of food preferences, it is estimated that, until 2022, 80% of the market for meat production will be in developing countries. The biggest problem is the availability of natural resources: to assure the same nutrition with a diet of animal origin, it would take seven times the resources that would be necessary for a vegetable diet.

Considering that the necessary food production increase to feed the growing population is a challenge due to the limited resources, the change of food preferences increases this challenge [12].

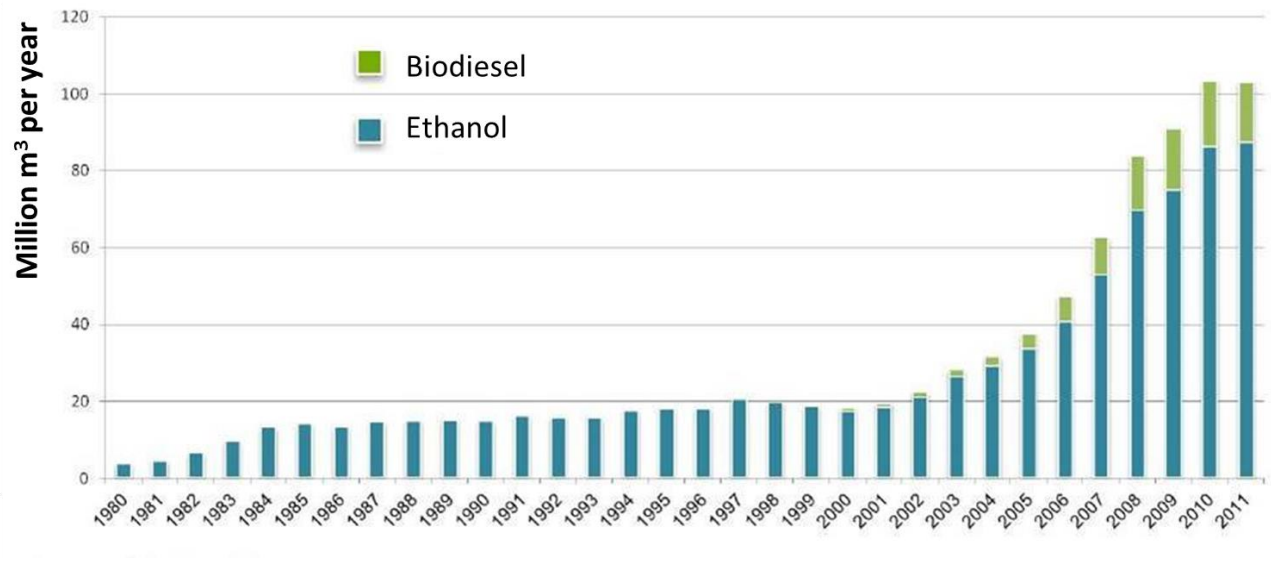

Figure 4. Biofuel production trend from 1990 to 2011 for Ethanol and Biodiesel [27].

4. Propositions for facing the challenges

As a strategy for facing the challenges of food security, countries should try to intensify production of the necessary food staples in their own territory, in order to reduce the import dependency and market volatility.

In this sense, the family farming by small- and large-scale farmers is a very useful agricultural production form, which is managed by the family unit carrying out the farm production relying mainly on family labour. This production form contrasts to investment or corporate type farm enterprises, with the main purpose of investment recovery and profit maximization. Nowadays, family farming is not only the highest contributor to food production at a global level, but also the predominant way of making a living in rural areas of many countries. Family farming, apart from assuring an economic income and improving the livelihood of the farmer's family, also has a long term interest. Therefore, it may care more about natural resources for future generations rather than only focusing on the increase of a short term economical profit, but also on the reduction of risks, for instance, with a diversified production. In times of climate change, this is a better coping strategy than specialized production and mono-cropping [32].

However, due to major weaknesses in the conventional tillage agriculture as was explained in the earlier sections, continuing to rely on 'business as usual' for further intensification of production is not an option for meeting future food needs sustainably. An alternate paradigm based on an ecosystems approach must contribute to meeting future food needs as explained in the following sections.

4.1. Sustainable intensification paradigm

In order to face the challenges of intensifying food production, necessary for feeding future generations, like saving and protecting limited natural resources, the United Nations' Food and

Agriculture Organization (FAO) suggests a change of paradigm: from an agricultural production that follows the model of the conventional Green Revolution agriculture to a sustainable intensification model [4,33]. The Green Revolution paradigm defines a production intensity through the use of inputs and considers the environmental damage as inevitable collateral effects of this production, which can be reduced but not completely avoided. This model does not seem to respond to future challenges, as the increasing level of global agricultural soil degradation keeps demonstrating.

The sustainable intensification paradigm uses natural ecosystem processes for reaching a high and intensive production, and uses technologies and inputs, only in a way that they do not interfere permanently with nature. While equal or higher levels of production are reached, compared to the Green Revolution agriculture, the environmental impacts of the new paradigm can be kept below the threshold of the natural recovery of ecosystems. In this way, besides achieving a highly intensive production, the protection of natural resources and the improvement of environmental or ecosystem services are possible at the same time and in the same geographic area [6,34].

The main focus in this alternate system is on soil and soil functions, being the most vulnerable components of the agricultural ecosystem because of their extremely long time for recovery. Therefore, the sustainable intensification is based on an agricultural system of no tillage, known as Conservation Agriculture (CA). It is defined by three interrelated principles with synergetic effects that are permanently and simultaneously applied [15,35] using locally formulated practices:

1. No or minimum disturbance of soil permanently with no tillage and direct sowing.
2. Constant cover of soil surface with organic matter, for instance, plants, crop residues or stubbles.
3. Crop diversity in sequence, rotation or association with annuals and perennials including legumes.

The above three principles of Conservation Agriculture can be applied in practice, along with other good agricultural practices of crop, nutrient, water, pest and energy management, to all crops in all land-based production systems, and at all operation scales, from the small farmer that uses manual implements up to the great extensions of land where big machinery is used. This type of agriculture, when adequately established, results in an increase of production, at reduced cost and input use, and in the increase of the biodiversity within the systems. It keeps soil and water in the watersheds, facilitates the competitiveness of agricultural production and adaptation to climate change [36–38]. Compared to tillage based systems it also facilitates the integration of other production sectors, such as livestock production and agro-forestry systems, orchards and plantations, and mixed systems. It also reduces environmental impacts and vulnerability of production systems during times of climate change, compared to specialized systems, and increases agricultural production and family income of producers [34].

Conservation Agriculture characterizes a paradigm change towards a true agro-ecology and a sustainable intensification. It is actually the core concept for this new paradigm and the reason which makes the combination of high production intensity, high delivery on ecosystem services and low ecological footprint possible [30,34,39]. CA is promoted by FAO as can be seen in the publication "Save and Grow" [11,33]. There is extensive empiric evidence for the benefits of Conservation Agriculture in the actually accelerated exponential adoption rates in many parts of the world, happening mostly under the leadership of farmers' organizations. Conservation Agriculture was practiced in 2015 on 157 Mha, corresponding to 11% of the global cropland with an annual growth rate of nearly 10 Mha. It is practiced in all land-based agro ecologies, with 50% of the CA areas distributed in developing and 50% in industrialized regions [40,41].

4.2. Changes of paradigm in agriculture and in the economic models

These changes applied in the agricultural production system do not only represent the inclusion of some good practices, but rather represent a change of paradigm, including of economic models sustaining the food and agriculture systems. An intensive production should no longer be defined by the use of inputs alone, but by its production performance and sustainability. Many economic concepts that are currently accepted, may change, such as in the case of economics of scale or the preference for a specialized production, in single crop or livestock production.

A diversified no-till CA production, and the greater national and international food and agriculture systems built upon it, could be more interesting economically in the longer term, reducing the production costs, as well as the overall production risks and negative externalities. Such a diversified production model can also improve food and nutritional security and protect natural resources with lower costs and higher profit [42]. With an integration of different production sectors, particularly the crop-livestock integration, ideally complemented by tree components, such diversified productions systems might also respond better to the consumer preferences regarding products of animal origin, avoiding the environmental challenges created by concentrated and specialized livestock production systems [43].

Thus the economics equation of the new paradigm does not only include yield that is produced with maximum efficiency and resilience, but also minimum environmental cost and with sustainability, in order to achieve the desired level of intensification. However, without the support of science, policy and institutions, this paradigm change is not possible [42].

5. Conclusions

The world is now facing a serious challenge of moving away from the degrading conventional tillage agriculture to a different paradigm of Conservation Agriculture to reverse the trends of land degradation and losses on productivity, re-establish sustainable production systems for intensification, and build efficient and resilient food and agriculture systems for the future to meet food security and industrial needs. Conservation Agriculture, which combines the ability to intensify sustainably with the delivery of ecosystem services is now (2013 update) spread across some 157 Mha globally, and is increasing at the annual rate of 10 Mha.

Food security in all countries stands to gain from the adoption of Conservation Agriculture. In the developing regions, CA offers greater yields and profit with less resources and decreased land degradation. In industrialized regions, CA can improve profit, sustainability and efficiency at high yields with less land degradation and environmental pollution. Policy and institutional support (including science and education) is needed to advance the spread of CA worldwide and establish food security as a function of sustainable production intensification.

Conflict of interests

Both authors declare no conflict of interest in this paper.

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