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Editorial

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A global challenge for the coming decades is to feed the world in a sustainable way. This will require major steps forward across the food production chain, including plant breeding, farming practices, and storage and logistics. Sustainable agriculture requires the implementation of agro-ecological and agronomic knowledge and methods in combination with optimal plant material, optimal in the sense that it is most suitable for a certain place, in a particular farming system, and in relation to market demand. To breed such plant varieties plant breeders need to employ the largest toolkit possible [1]. Among the wide array of tools available to the breeder, genetic modification (GM) receives most attention in public debates on sustainability.

In Europe, practically the only GM crop sown, Bt MON810 maize, was grown on 114,000 ha (<1% of total European maize acreage) in 2011, with only Spain having a significant proportion of the maize acreage occupied by the Bt crop, i.e. 28% [2]. On the other hand, a very large part of imported feed, particularly soybean, is GM and so livestock production in the EU depends on GM products. The debate on European cultivation of GM crops appears to be in a gridlock in many EU countries and in European policy-making. The European Commission has initiated the development of a framework for including socio-economic sustainability in the evaluation of GM crops, in addition to safeguarding environmental and health safety issues [3]. The primary aim of this initiative is improving insight in the socio-economic impact of GM crops. Such science-based insight might help to overcome this debate gridlock by facilitating the development of new viewpoints. In this context, the Netherlands'Ministry of Economic Affairs, Agriculture and Innovation funded a broad literature review on the sustainability for current GM crop cultivation. This review took into account the experiences of 15 years of commercial GM crop cultivation with regard to three sustainability dimensions, i.e. social (*People*), environmental (*Planet*) and economic (*Profit*) [4].

The Dutch government has sent the results of this review to the European Commission as input in the development of the evaluation framework for GM crops. Moreover, the results have been discussed with Dutch stakeholders in a workshop in 2012 [5], and subsequently in several debates and in the news media in the Netherlands. From these events we learnt that a societal commitment is arising which allows a broader discussion with more nuance to GM crops than a simple yes or no when it comes to their application in agriculture. We think this development in the societal debate in the Netherlands may also be relevant to other countries, for other constructs, and for other crops. In this Letter to the Editor we will first summarize the results of the literature review. Second, we will describe stakeholder responses to these results and discuss these with respect to current scientific knowledge. Finally, we will propose a way forward in the societal debate around GM crops by reframing this debate within a broader discussion on what sustainable agriculture in future should look alike.

1. Review of sustainability of current GM crops

The literature review [4] built on existing sustainability schemes and produced a series of indicators (Table 1) which also included elements from international standards, e.g. for *People* based on the Universal Declaration of Human Rights (UDHR), using conventions and standards like those from the International Labour Organization to be able to apply the UDHR principles in the context of agricultural production. As knowledge and viewpoints change and technology progresses, the desired level of each indicator is a moving target. The review compared GM crops to the current conventional crop production, except where GM crop adoption has been so extensive that data on non-GM cultivations in the same region can only be obtained from the recent past. For instance, in the US and Argentina, 93% and 99%, respectively, of soybean growers used GM varieties in 2010 [6]. Food and environmental safety were not part of this review, as they are already part of the assessment for legal acceptance of GM crops for cultivation and/or import into the EU.

The review clearly showed that the sustainability of the presently cultivated GM crops varies with crop species, GM trait, region and institutional context, and also depends on other factors, such as time since first introduction and year-to-year variability due to, for example, weather conditions and disease pressure. This is equally true for GM and non-GM cultivations. The results do not justify *a priori* exclusion of GM technology from the further development of sustainable agriculture. Non-GM cultivations cover a wide range of practices, including forms of high-input intensive agriculture, integrated systems and organic agriculture. Differences between non-GM cultivations are large, particularly when also local traditional systems are taken into account. The differences between GM and non-GM cultivations are mostly smaller than those among cultivations (GM and/or non-GM) in different regions. We illustrate this general result with data for cotton. Bt cotton was reported to increase yields, relatively to non-GM cotton, by 0 to 83%. However, national average cotton yields of main cotton producing countries in 2010/2011 varied almost seven times, from 252 kg/ha (Nigeria) to 1681 kg/ha (Australia) [7]. This shows that for yield improvements one needs to take into account a wide array of factors.

Finding relatively little difference in sustainability performance between GM and non-GM variants does not mean that the crop production system under scrutiny in general is sustainable. For instance, the strong expansion of the overall soybean acreage, GM and non-GM, in Latin America had quite a number of environmental

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Table 1
Indicators used to operationalize the three sustainability themes People, Planet, Profit.

People	Planet	Profit
Labour conditions	Production efficiency (use of land, water, biocides, nutrients, and energy)	Farm income
Land rights, rights of indigenous people and community rights	Soil conservation	National income
Freedom of choice	Water conservation	Economic welfare distribution
Competition with food production	Biodiversity	Financial and other risks
Contribution to livelihood of producers and local communities	Climate change	

and social-economic impacts of which some may be regarded as negative for particular sustainability indicators, such as biodiversity. The Latin American soy production was an example of an agricultural development in which the specific role of GM cannot forthrightly be disentangled from other drivers. Herbicide-tolerant transgenic soybean varieties fit well in large-scale soy production. However, the main economic driver for this expansion appeared to be the worldwide increasing demand for soy products. The review concluded that, at most, the availability of GM soybean has facilitated the expansion of soybean acreage, for large-scale cultivation of non-GM soybean has also expanded enormously, e.g. in the northern Mato Grosso province of Brazil [8].

Bt crops conferring resistance to serious insect pests generally improve sustainability with regard to *Planet* aspects. The introduction of Bt crops has generally included a high dose/refuge strategy to slow down resistance development in the pest insect that would harm Bt crop effectiveness and likely the accompanying decrease in insecticide usage [9]. This strategy is an example of *good agricultural practice*, based on the best of agronomic and agro-ecological knowledge available. With herbicide-tolerant crops, such as Roundup Ready soy, less attention has been paid to such programmes. Consequently, in areas where farmers relied solely on the flexibility in weed management of a single herbicide (glyphosate), weeds have developed resistance against the herbicide. This appears to have reduced or even nullified the initial sustainability gains achieved by the use of a herbicide with a lower toxic impact (glyphosate) and by the facilitation of conservation tillage, as herbicide usage and impact have gone up in recent years [6,10,11].

With regard to *Profit* and *People* themes, the contribution of GM crop production to sustainability is also dependent on local legal and institutional systems, complicating general conclusions [12]. For example, whether and to what extent intellectual property rights (IPR) linked to a certain event generally impacted on the availability of seeds optimally adapted to local conditions as well as the contribution to livelihood of producers and local communities, could not be straightforward answered. The ability to choose for good quality, locally adapted Bt seeds in India appeared to be initially hampered by a quick succession of seed brands with a poorly verifiable varietal identity. Thus, farmers were not able to test the efficacy of new seed varieties for themselves, while there was also no accompanying reliable information on the performance of the seeds that could compensate for this [13]. At the same time, illegal seed markets sometimes were helpful in making available Bt varieties to local resource-poor farmers, but also contributed to problems in obtaining reliable good quality seeds of locally adapted varieties. Currently locally adapted varieties with Bt traits are widely available, including cotton varieties with locally developed Bt events, partly derived from public breeding programs [14]. Although variation exists among farmers and regions, resource-poor farmers generally profited from the use of Bt cotton [15].

2. Stakeholder responses

The results of the review were discussed with 20 societal stakeholders, amongst them farmer representatives, retail and other product chain parties, and NGOs in the field of nature, environment and aid to developing countries. In general, most societal stakeholders acknowledged the conclusion that performance in sustainability indicators is not simply related to a single factor, such as whether or not genetic modification was part of the breeding process that resulted in a specific cultivar [5]. These stakeholders addressed also the question whether measures could be envisaged that would stimulate farmers to strive to an optimal integrated mix of agronomic measures, and dampen the dependence on simple single measures, such as relying on a single herbicide for weed management. Several groups indicated their ambition to participate in a brain trust to jointly explore what sustainable agriculture in the future should look like. In such an exploratory approach the possible contributions of conventional and GM crop varieties should be evaluated for what it basically is, a choice of the most optimal plant material, in relation to agronomic optimization in various forms of agriculture, including integrated agriculture, and next to organic agriculture. During this workshop and in the subsequent public debates Greenpeace remained adamant against the commercial use of GM crops.

Three arguments are central in the Dutch debate on GM crops at present. The first argument refers to the uncertainty linked to insertion of DNA constructs by means of genetic modification. This uncertainty is thought to increase the risks of unforeseen and adverse effects, such as the production of allergens. Basically, this is an unsolvable and irrefutable argument as it is at the heart of the scientific method, which by definition never generates 100% certainty. However, the procedures that GM crops have to pass before they are permitted to be released, encompass all safety assessments that large panels of experts and competent authorities have enlisted from a large body of scientific literature and experience and as a result, approved GM crops have been checked more thoroughly than any variety released for food and feed purposes in the history of plant breeding, and they are therefore regarded as safe by governments.

The second argument refers to concepts of Naturalness, as e.g. being favoured in organic agriculture. This argument points to a preference for a type of agriculture that is less focussed on (bio)technology and economies of scale, and instead aims at using agro-ecological measures as much as possible. As discussed above, good agronomic and agro-ecological practice is a prerequisite for every form of agriculture.Thus, an approach prioritizing agro-ecological measures is not inherently incompatible with GM crops. Growing resistant varieties may importantly add to the impact of agro-ecological measures. For example, Bt cotton brings down the less sustainable option of insecticide use, in turn promoting the occurrence of natural enemies of pest insects not targeted by the Bt. This benefits Integrated Pest Management (IPM) [16].

The third argument in the Dutch debate refers to power relationships in market chains, and more specifically to power that is linked to IPR. It expresses a fear that farmers and consumers become totally dependent on large biotech companies for food production, as the introduction of GM varieties is considered to change power relationships. Introduction of GM crops indeed changed the relationships between seed companies and breeders. For instance, US farmers used farm-saved seeds in soybean cultivation, but this was not possible anymore with GM soybean as the Roundup Ready trait was patented, thus turning farm-saved seeds into an infringement [17]. This is not an entirely new development for farmers, as also the choice for hybrid varieties was accompanied by losing the option of seed saving, e.g. with maize in the US in the 1930s. For breeding companies, a form of IPR is important to ensure a return on investment when developing new varieties, which not only applies to GM traits as breeding companies also seek protection for other traits introduced through modern non-GM breeding methods. The development of GM crops is particularly costly and this has been one of the drivers of consolidation in the breeding industry. The review [4] showed that the simultaneous trends of consolidation in the breeding sector and the use of patents may lead to re-distribution of welfare gains in the direction of the patent holders. However, in a competitive market, welfare gains are more equally distributed and the value of a patent is determined by the benefits of the patented product. GM traits are only successful in the long term if they are clearly beneficial for the farmers, for instance, by improving their flexibility, reducing their production risks, and/or improving yield and quality of the product, which were strong incentives to use herbicide-tolerant crops. Indeed, farmers pay different 'technology fees' for GM seeds, which appears to be related to expected profits under local conditions. For instance, prices for Bt seeds in Spain varied between regions, seemingly in line with local infestation levels of the targeted insect, the European corn borer [18].

Beyond the realm of patents of large companies on gene constructs, small and medium-sized breeding companies can in principle also apply genetic modification. Research institutes may make available isolated useful genes by means of non-exclusive licenses to breeding companies, institutes or even governments. Wageningen University is currently developing models for such non-exclusive exploitation, to be applied for sets of *R* genes from wild potato species that confer resistance against *Phytophthora infestans* [19]. We expect that the discussion about patents in relation to plant variety protection will continue and that in the future alternative IPR models may be developed that will meet some of the criticisms on the current exploitation of GM crop varieties exclusively by a few multinationals. Another development relevant to a more equal distribution of power is the use of joint data sets in the registration process by several companies. For example, the United States Department of Agriculture explores in programmes at the National Institute of Food and Agriculture whether such joint use of data will lead to a decrease of registration costs and thus to lower thresholds to marketing GM crops.

3. Stakeholder participative approach

Given the strong commitment in Dutch society to further develop a more sustainable agriculture according to the three sustainability dimensions People, Planet, Profit (operationalized in Table 1), we propose to first discuss with stakeholders what types of sustainable agriculture are desired to feed the world population in the future. The next step will be to translate this into concrete combinations of the best agricultural and agro-ecological knowledge and methods, in combination with the best crop varieties, optimally adapted to local growing conditions and fitting in local institutional and societal context. No technology, including genetic modification, should be excluded *a priori*. In this process scientists, the government, companies, farmers and NGOs each contribute, based on their knowledge, experience, and social responsibility. Importantly, we contend that this combination of contributions should be sought after in very practical cases: for one area, one crop, one production system and one product-market chain at the time. A case could be for instance the potato production on clay soils in the Netherlands for the Dutch consumption market. We think that such a participatory approach with societal stakeholders that commit themselves to further development of sustainable food production, will mean a catalysing step forward in the societal debate around GM crops and sustainable agriculture.

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