EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

MINIPAPER: “Improved Varieties and New Crops”

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1. Introduction

Water stress is the most limiting factor for agriculture worldwide. Moreover, the increasing intensification of crop production together with the water scarcity problems in many agricultural areas, is leading to soil impoverishment. This results in a decrease of yield and/or in an increasing difficulty in obtaining average harvests, not to mention rural depopulation. In Europe the area with the highest risk of rural depopulation is located in the south, a geographically defined area which consists of the Mediterranean region. At the same time, this is an area with major problems of water scarcity. In order to ensure sustainable development it is core to define strategies which stabilize agricultural production while protecting soil quality in areas where water is limiting.

It is widely accepted that greater varietal and species diversity would enable the system to maintain productivity over a wide range on agro-ecological conditions, although, greater diversity does not necessarily means greater productivity or better adaptation. When tackling water scarcity, crop and varietal selection is crucial for farmers in order to adapt their production to the available resources. With both, traditional and biotechnological aided- plant breeding, it is possible to obtain varieties which cover three different lines: better productivity under adverse environmental conditions, less water requirement and less environmental impact. Moreover, there are other research lines such as new productive crops and soil improver crops.

Presently, the majority of the productive crops' breeding activity is based on the private sector, even with the use of joint ventures with some public research center. This may be one of the reasons why the market evolved so fast. The European seed market is of around 7000 million euros (39% cereals and legumes, 26% corn, 14% potatoes seeds and 11% vegetables). In terms of use of water, in less than 30 years food production by cubic meter of water has increased around 19% in wheat, 63% in tomatoes, 75% in orange production and 215% in olive production. Moreover, around 40% of the increase in production is related to improved varieties (FAO, 2009[1]).

An example of continued improvement in the market is the case of broccoli in the south east area of Spain. In the 80's, broccoli production for fresh market was around 10000kg/Ha and the quality was not ideal due to the low availability of water and the salinity in the soil. Just with the introduction of improved varieties such as *Brassica oleracea* L. var. *Itálica 'Marathon'*, the production improved to around 13000kg/ha using the same amount of water. Moreover, there was a complete improvement in the quality standards. Presently, Spain produces more than 50% of the total production of broccoli in Europe and the standard production for fresh market is around 16000kg/ha. In 2003, new varieties (*'Parthenon', 'Naxos', 'Forester'* and 'Monaco' among others) were introduced improving not only production but also extending the production period because of their tolerance to drought, heat, and salinity (Dominuez-Perles, R. et al., 2011[2]; Salguero, J. et al., 2011[3]). The main success of the new varieties is partly due to the high water use efficiency.

Plant breeding for drought resistance

Drought resistance has long been part of the aim of plant breeding. Above all because an important factor of yield stability is coping with abiotic plant stresses and therefore drought.

First, crop improvement was based on selecting plants which apparently perform better under water stress. After years of selections, this material presents an adaptation to dry conditions. Later, with the emergence of the Mendelian genetics, elaborate biometrical and statistical methods for quantitative genetics analysis were developed to enable selection for yield and yield stability. This together with an increased knowledge in plant physiology led to yield-based selection programs based on physiological selection criteria for stress resistance. With the venue of molecular methods, such as marker-assisted selection it was possible to facilitate more efficient selection for distinct components of abiotic stress resistance. In the last decade, biotechnology is experimenting with genetic transformation to develop new varieties which may be able to give additional genetic for drought resistance (Blum, A., 2011[4]).

Enhancing water absorption by the roots is one of the main mechanisms by which plants can maintain their water content under stress conditions. Within the plant, short-distance transport of water and transport in non-vascular tissues occurs across cellular membranes involving proteins called aquaporins (Maurel et al., 1993[5]). Therefore the importance and the significant implications of aquaporins on crops could be a target point for increasing water stress resistance (Carvajal et al., 2000[6]). In fact, aquaporins are related to the regulation of

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the hydraulic conductivities that finally affect plant water uptake ability. For this reason, aquaporins as marker of selected crops were obvious candidates as breeding targets to improve abiotic stress tolerance (Martínez-Ballesta, M. C. and Carvajal, M., 2014[7]). Other solutions are based in increasing the plant content in osmolites (small hydrophilic molecules which prevent water loss), the antioxidant response or the abscisic acid depending signalling (Fang, Y. and Xiong, L., 2015[8]).

In spite of all these efforts, few cultivars have been developed specifically for drought tolerance or resistance and their efficacy has seldom been proved in farm conditions. This minipaper discusses the main limitations and potential solutions for obtaining improved cultivars to tackle water scarcity conditions.

2. Limitations

Related to methodology and knowledge

When phenotypic selection was the only tool available to improve yield under drought, the improvement in crop yield observed were likely due to an increase in yield through the pyramiding of yield traits. Thus breeding for high yield under stress is not an easy task, particularly in rainfed conditions of variable rainfall. Field testing to demonstrate improved crop performance under drought conditions is challenging.

Since the development of biotechnology, it was proposed the identification of drought tolerance-related trait and the manipulation of the corresponding genes using markers assisted selection and/or gene transformation, therefore facilitating the work of breeders (Cativelli et al., 2008[9]). However, little success has resulted from traditional, markers assisted selection and/or gene transformation in this field. Currently, researchers place their trust in phenotyping contributing to improved predictions about field performance.

The problem behind this apparent lack of success was to identify the genes whose function is limiting under drought stress. Most of the breeding projects have been developed under a trial-error basis. Nevertheless, the use of strategies based on screening for genes able to give tolerance under stress conditions has render interesting results that at this moment are under development, as increasing the antioxidant capacity of plants by increasing the amount of sulphur amino acids (Mulet et al., 2004[10]). Other strategies are based on improving the antioxidant capacity of plant organs prone to damage by stress, such as the root nodules, in this regards, glutathione peroxidases has been shown to have a pivotal role in stress resistance (Matamoros, 2015[11]).

Related to the Private Sector

As pointed above, most breeding field occurs in the private sector. This fact is related to a certain number of limitations. The most important one is profitability. Companies tend to invest more in those crops with either a higher value in the market or which are widely produced. Therefore, some local varieties with a small market niche may be in risk of being left apart.

Furthermore, from the private sector point of view, there are two controversial issues which have been identified as limiting for improving crops. The private sector claims that regulation should evolve together with research and development. This is related to the European legislation about genetically modified organisms. Many organisations are against these technologies and highlight many ecological risks. Most of them are related to the risk of genetic contamination which might include loss of original diversity of wild relatives of crops trough gene flow, damage infliction to non-target organism, and erosion of crop varietal diversity. In this regard, the private sector is asking for a legislative framework stable and proportioned to a risk level based on scientifically proven parameters.

The second controversial issue identified as limiting is related to intellectual property rights. The private sector claims that without securing the returns from the investments in research and development there will be no improvement in the matter. However, again some organisations are against this issue arguing that this measure constitutes an appropriation of a natural product, often result from the breeding done by farmers in the last centuries. To solve the controversy, it is important to define what is a natural product (with a particular trait) and what is the improvement due to a breeding effort, and therefore, if it is liable to be protected by the intellectual property rights.

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Nevertheless, the private sector has succeeded in offering products developed specifically for drought tolerance. For example, the DroughtGard Maize was developed by a joint venture between BASF and Monsanto and, according to their research, these cultivars increase productivity under water stress (Nemali, 2015[12]).

Related to the Farmer

From the farmer’s point of view, crop and variety election are often more related to productivity, easy handling, quality standards and resistance to pathogens and pests than to the water efficiency. This is promoted by the fact that sometimes water prices do not represent an important part of the production costs.

Related to Sustainability

Crop genetic diversity is considered as a source of continuing advances in yield, pest resistance and quality improvement and thus as a contributing force to sustainable agriculture. However, from the sustainability point of view, it can be argued that varieties which are more productive in extreme conditions do not necessarily mean a reduction in water consumption but just a higher production using the same amount of water.

3. Gaps in knowledge and potential solutions

New crops.

Some species have been identified as particularly interesting due to their adaptive response to water stress conditions. Some examples can be found in the Mediterranean region where plants have developed different strategies to respond to drought, including morphological, physiological and phenological adaptation.

There are two types of plants which are especially interesting when talking about introducing new crops, these are Xerophytes and Halophytes. These species have developed different strategies to adapt to very extreme conditions of water stress and salinity respectively. However, while some of these speces such as Salicornia have been already assessed for oil production, biofuel and food production, many others have not been identified for a specific industry. Moreover, those edible have a very small market niche. That is why the main importance in this regard is how to exploit this kind of crops. Furthermore, in the specific case of halophytes, it has been identified a possible bio-remediation potential as some of them are able to extract salts from the soil (Sulian, Lv. et al. 2011[13]). Even thought, presently, the extraction proportion is not relevant for them to be included in the rotation plans to contribute in improving or maintaining the soil quality, these traits may be promoted via breeding techniques. What seems to be clear is that halophytes can be used in regions with poor proportion of agricultural development due to their salinity problems.

As the average cost of introducing a new variety in the market is around 1-1.5 million euros and it lasts around 10-12 years, it seems difficult that this could be afforded with public funds. A possibility could be to study the matter together with private companies in a private-public partnership. Again, the main issue is to find a private company interested in this kind of joint venture. It has to be considered that this kind of research implies a high risk of failure. This is why some of the research toward new drought tolerant crops is currently being made by public companies. Examples of this can be found in Argentina where it has presented a drought resistant soy (La Nación, 2015[14]) or in Indonesia where a drought resistant sugar cane will be commercialised in the close future (The Jakarta Post, 2013[15]).

Improved varieties

Mutant collections obtaining, new tools for both traditional and new breeding technics, and molecular markers have been identified as the main technological demand by the seed industry for developing new varieties. However, to the products of breeding programmes using most of these techniques require the establishment of a clear regulatory framework (Plataforma Tecnologica de Agricultura Sostenible, 2015)[16].

Local Varieties

Some public research centres are focusing their work on local varieties and crops which are of minor interest for the private sector. Their effort has been of importance since by doing that they are also keeping the gene pool of the crop. The main difficulty is to place a product in such a small market niche. This kind of effort may be promoted while keeping the focus on obtaining a marketable product by, again, private-public partnerships. Moreover, calls for this specific purpose under H2020 work programme may be of great help.

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Molecular targets

The multiplicity of aquaporins isoforms and their involvement in the response to stress depend on the nature, intensity and duration of the stress, necessitating a selection "on demand" of the aquaporin genetic manipulation to solve a specific environmental problem for each particular cultivar.

In the recent years scientist have elucidated the molecular basis of the plant response to drought, including the identification of the genes responsible for the reception of the signal triggered by abscisic acid, the hormone that is in charge of the plant response to abscisic acid (Rodriguez et al., 2014[17]). This opens a new possibility, the development of bioestimulants based in natural products able to activate proteins (such as the PYR abscisic acid receptors or the C"-domain related proteins) which improve the natural plant response without genetic engineering.

Measures to Influence Farmer Decision Making:

Price Policies

As have been said before, it is important for farmers to prioritise water conservation over other aspects. This effort requires a work of awareness-raising about the real value of water and of translating it into costs. It is needed to change water costs policies in order to make people conscious about its value and force them to adapt the most water efficient measures. At the same time, it is needed to adapt the legislative system to organise the monitoring labour. Without an evaluation of farm practices by an institutional actor, it will be really difficult to ensure any correct water-rationing practices at farm level.

The change in policies that is needed to improve the situation is not politically welcome. In fact these kind of measures are unpopular among not just farmers but society in general. Again, an awareness-raising work is needed to make farmers conscious of water problems and the influence of their management practices. Moreover, it is important to make society conscious of what really is nowadays agriculture and how important it is.

The Role of Advisors

When it comes to dissemination of results regarding not just water efficiency but any other crop or variety advantage, the role of the advisor either private or as a public organisation is crucial. It is important to assist farmers in order for them to adapt the most suitable crop and variety according to their needs and specifications. This work needs to evolve as fast as the market which is in continuous change with the introduction of new varieties every year. Moreover, the impartiality should be guaranteed.

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