Selection of Key Characteristics for Crops to Deal with Climate Change Through Quality Function Deployment

A. Robayo Avendaño and D. Prato Garcia

Abstract

The use of genetically modified (GM) varieties represents the best strategy to adapt to climate change. The use of quality function deployment (QFD) provides a simple tool for decision taking. The characteristics of water, soil, chemical fertilizers, pesticides, and herbicides are indispensable criteria in the selection of adaptation alternatives.

Keywords

Quality function deployment • Conservation agriculture • Organic agriculture • Genetically modified varieties • Climate change

1 Introduction

Although in the last years, the productivity of crops has increased notoriously, their yield and stability are affected by the particular impact exerted by climate change in the geographical zone where they are developed. In low latitudes (tropical regions), the climate change effect could be more adverse as a consequence of the temperature increase and the development of extreme events like droughts and floods. This phenomenon also impacts biodiversity, the soil, water availability; likewise, it affects how pests are dispersed and determines the use of agrochemicals (Mall et al. 2017). As can be inferred, this will have a dramatic impact on the use and distribution of resources such as soil and water, the cost of food, and on the productivity and rentability of crops meant for energy production.

Currently, climate change adaptation alternatives are available, such as inclusion of improved agricultural practices (also called conservation agriculture), organic agriculture, and use of genetically modified (GM) varieties (Camarotto et al. 2018; Hole et al. 2005; Adenle et al. 2015). Conservation agriculture (CA) aims at reducing CO_2 emissions and the impact of crops on soil erosion through crops rotation, protecting the soil with vegetal cover generated by the same crop, and the optimized use of both fertilizers and herbicides (Camarotto et al. 2018). On the other hand, organic agriculture (OA) develops crops without the use of artificial chemical products. This alternative reduces notoriously soil erosion and emission of greenhouse gases (GHG); however, it is limited by the low capacity to supply nitrogen to the plants (Hole et al. 2005). The GM varieties are developed by inserting genes of a donor organism to a receptor one using biotechnological techniques; this genetic transfer provides the receiving organism with a new characteristic that can include resistance to insects, tolerance to herbicides, and tolerance to varying climate conditions, among others (Adenle et al. 2015).

Although there are different tools to assess the impact of climate change on crops, the methodology known as quality function deployment (QFD) is more simple and efficient because it translates the needs or requirements of the interested parties in technical characteristics or alternatives that will respond to a necessity. Based on the relevance of the topic, this work is aimed at applying the QFD methodology for the selection of the best adaptation alternative to climate change in crops (food or bioenergetics) analyzing three adaptation strategies (conservation agriculture, organic agriculture, and sowing of GM varieties). For this, we took as reference five key requirements for a crop (water, soil use, herbicides, pesticides, and fertilizers).

A. Robayo Avendaño
Facultad de Ingeniería, Universidad Santiago de Cali, Campus Pampalinda, Calle 5 No. 62-00, Cali, Valle del Cauca, Colombia

D. Prato Garcia (✉)
Facultad de Ingeniería y Administración, Universidad Nacional de Colombia—Sede Palmira, Carrera 32 No. 12-00, Chapinero, Vía Candelaria, Palmira, Valle del Cauca, Colombia
e-mail: dpratog@unal.edu.co

© Springer Nature Switzerland AG 2020

V. Naddeo et al. (eds.), *Frontiers in Water-Energy-Nexus—Nature-Based Solutions, Advanced Technologies and Best Practices for Environmental Sustainability*, Advances in Science, Technology & Innovation,
https://doi.org/10.1007/978-3-030-13068-8_18

2 Materials and Methods

Review of the literature and the confirmation of a focal group of experts were indispensable to establish the scores for each variable integrating the QFD. Initially, we *identified the needs* and translated in our study as the requirements of crops under changing climate conditions (water, soil, herbicides, pesticides, and fertilizers). Crop requirements with a weight closer to one (1) were considered more important, whereas those close to zero (0) were irrelevant or less important (Table 1). By means of group discussions, the adaptation strategies to climate change were filtered and those that could be incorporated to the productive practices in emerging economies were *selected* (conservation agriculture, organic agriculture, and GM varieties). The next step was to establish a *matrix of relations*; for this reason, the experts were asked to perform an evaluation granting a score (one, two, or three) to each relation (Table 1). If the variable affected highly the performance of the crop, a score of 1 was granted, if, in contrast, the use of the variable resulted not relevant for the crop's performance, the score was of 3. Finally, if the variable affected in a limiting fashion the performance of the crop, the assigned score was of 2 (Table 1). To select the most convenient adaptation alternative, we calculated the absolute weight (AW) (Eq. 1); in this equation, I represents the importance of the requirement and S the assigned score by the group of experts to each alternative. Taking as reference the AW, the relative weight (RW) was calculated (Eq. 2). Priority (PRY) was defined consecutively, granting the first option to the RW of highest value and the last option to the RW of lowest value.

$$PA_i = \sum_{i=1}^{n} I_i P_i \tag{1}$$

$$PR_i = \frac{PA_i}{\sum PA_i} \tag{2}$$

3 Results and Discussion

In this study, *CA* obtained the lowest absolute and relative weights, 1.7 and 0.26, respectively. For *CA*, the water factor resulted in critical for the development of the crop because crops do not present tolerance to water stress. Regarding use of soil and agrochemicals, *CA* incorporates strategies like crop rotation, use of the residues generated by the productive process to minimize both consumption of agrochemicals (pesticides, herbicides, and fertilizers) and mechanical procedures like cutting with rotating blades to control undergrowth; notwithstanding, the use of agrochemical products is still needed for the adequate development of the crop. For this reason, *CA* presents a disadvantage regarding the reduction of GHG emissions as compared to other alternatives (Camarotto et al. 2018). The *OA* is an attractive alternative (AW = 2.2 and RW = 0.34) as it uses organic fertilizers and pesticides, which affect less the biological activity and soil fertility; additionally, it promotes the use of good management practices for the soil and water (crop rotation, use of mixed crops, and farming techniques), which influence notably the environmental sustainability of the crops (Hole et al. 2005).

The use of *GM varieties* resulted in the most outstanding alternative (AW = 2.55 and RW = 0.40) as these include features of tolerance to drought and pesticides, which could make the growth of plants feasible under certain conditions (water stress and poor soils). Besides, it grants resistance to pest insects, leading to minimal applications of pesticides and reducing the impact on the environment. Our findings agree with those reported in (Adenle et al. 2015), as they recognize the potential shown by GM varieties addressed at specific characteristics for the adaptation to climate change, contributing to the reduction of GHG emissions by diminishing the applications of fertilizers and pesticides. The *CA* is assumed as a useful production system in the development of small-scale crops; however, its performance depends on

Table 1 Matrix of relations between crop requirements and climate change adaptation alternatives

Requirement	Importance (I)	Score assigned to the adaptation alternative (S)		
		Conservation agriculture	Organic agriculture	GM varieties
Water	0.40	1	1	2
Soil	0.30	1	1	2
Chemical fertilizers	0.20	2	3	2
Chemical pesticides	0.15	2	3	3
Herbicides	0.15	2	3	2
Absolute weight, (AW)		1.7	2.2	2.55
Relative weight, (RW)		0.26	0.34	0.40
Priority, (PRY)		3	2	1

its capacity to adapt to the conditions of the zone where the crop is sown (Camarotto et al. 2018). The *OA* is recognized as an environmentally friendly alternative, notwithstanding its benefits are limited by the location, climate, type of crop, and the applied management practices (Hole et al. 2005).

4 Conclusion

The QFD analysis reveals that according to the characteristics needed for a crop to be able to support changing climate conditions, the use of GM varieties could be the most convenient option. However, it must be recognized that the economic variables could also play a notable role in the selection of alternatives. Application of the QFD methodology together with the participation of a focal group of experts represents a valuable tool for decision taking in agriculture.

References

Adenle, A., Azadi, H., & Arbiol, J. (2015). Global assessment of technological innovation for climate change adaptation and mitigation in developing world. *Journal of Environmental Management, 161,* 261–275.

Camarotto, C., Dal Ferro, N., Piccoli, I., Polese, R., Furlan, L., Chiarini, F., et al. (2018). Conservation agriculture and cover crop practices to regulate water, carbon and nitrogen cycles in the low-lying Venetian plain. *Catena, 167,* 236–249.

Hole, D., Perkins, A., Wilson, J., Alexander, I., Grice, P., & Evans, A. (2005). Does organic farming benefit biodiversity? *Biological Conservation, 122,* 113–130.

Mall, R., Gupta, A., & Sonkar, G. (2017). Effect of climate change on agricultural crops. In C. Larroche, M. Á. Sanroman, G. Du, & A. Pandey (Eds.), *Current developments in biotechnology and bioengineering* (p. 850). Amsterdam: Elsevier.