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Sustainability Assessment of Highly Biodiversified Farming Systems: Multicriteria Assessment of Greek Arable Crops †

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Abstract: The intensive agriculture that is used in many countries has led to a reduction in biodiversity and the deterioration of the environment. Therefore, it is important to increase the adoption of cropping systems with high biodiversity. The objectives of the present study were the following: 1. assess the performance and sustainability of novel highly diversified production systems compared to the current traditional system and 2. provide quantitative economic and ecosystem service information for farmers, extension workers, and policy makers in order to support the development of sustainable and resilient high species cultivar/landrace diversification (HSD) production systems. The rotation of wheat–pea–barley was a system with low energy inputs and high outputs, significantly increasing the energy efficiency. Also, the same system demonstrated better economic and environmental indices, making it a suitable cropping system for Mediterranean areas.

Keywords: crop rotation; intercropping; pea; co-design; wheat

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1. Introduction

The wide use of intensive agriculture in many countries has had many adverse consequences as it caused an increase in soil salinity and the deterioration of plant growth environments [1]. The deterioration in plant growth environments is also exacerbated by climate change, such as the increases in temperature and changes in rainfall, which will make agricultural production even more vulnerable in the future [2,3]. To alleviate these challenges, it is necessary to use sustainable agricultural systems and increase the biodiversity of cropping systems.

The diversification of agricultural production systems implies forfeiting the economies of scale by increasing expenses per unit of output, reducing the efficiency of machinery, and applying less specialised knowledge and labour division [4]. The ecological benefits of diversified farming systems were found to be insufficient to outbalance the economic costs in the short term [5], even though many examples showed that diversified farming practices have the potential to lead to higher and more stable yields [6], increase profitability, and reduce risks in the long term [5]. Therefore, research on diversified systems requires short- and long-term economic analyses to identify efficient policy support measures.

The objectives of the present study were the following:

Assess the performance of novel highly diversified production systems compared to the current traditional system.

Provide quantitative economic and ecosystem service information for farmers, extension workers, and policy makers in order to support the development of sustainable and resilient HSD production systems.

2. Materials and Methods

The approach that was followed was an integrated approach that incorporated stakeholder expertise, analysis of empirical data, and quantitative modelling of the economic and agro-environmental performance of novel production systems. Furthermore, the quantitative data that were used for the modelling process of this study were obtained from previous, similar experiments of the laboratory in the same place and using the methodology followed by Rezgui et al. (2023, under review) [7]. This combination of sources allowed us to capture the short- and long-term effects of diversified production systems. The work focused on HSD arable rotations used in Mediterranean areas and especially in Greece. The work was organised by generating and assessing diversified crop rotations with the cropping system assessment framework. During the co-design process, three systems were developed: (i) Diversified system 1 (DIV1) was a wheat–oilseed rape–barley rotation; (ii) Diversified system 2 (DIV2) was a rotation of wheat–pea–barley; and the third diversified system (DIV3) was a wheat-intercropping of barley with common vetch–barley rotation. The three diversified systems were compared to a typical sole cropping system in the region of wheat and barley monoculture.

The indicators used to evaluate the four systems included energy efficiency, total renewable and non-renewable input energy per system, and pesticide load indicator, along with three sub-indicators (health load, ecotoxicity load, and fate load), and the economic performances of the four systems (farming profit, farming income, and farming cost).

3. Results

Energy-use efficiency was determined for the four systems, and it was found that DIV2 is the most energy-use efficient system, followed by DIV3 (Figure 1). These results were probably observed because the pea crop was more energy efficient due to a high grain energy output and low energy inputs when compared to the RS than the vetch–barley intercrop as well as the rapeseed crop (DIV1).

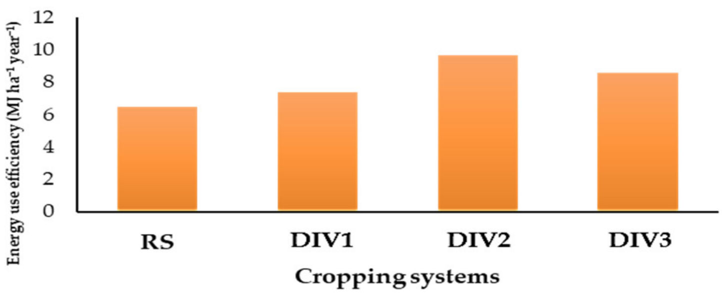

Figure 1. Energy-use efficiency of the four systems that were co-designed with the stakeholders of the agri-food chain.

The total renewable and non-renewable input energy per system was calculated and it was found that DIV1 was the one with the highest non-renewable energy input, followed by the RS. DIV2 and DIV3 were the ones with the highest renewable energy input (Figure 2).

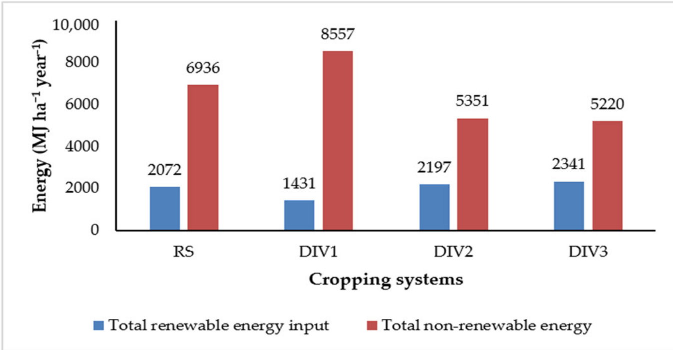

Figure 2. Total renewable and non-renewable input energy per system.

From the four systems that were assessed the system, the RS had the highest pesticide health load. This means that the pesticides which were used for this system type were the most toxic to humans compared with the pesticides used for other systems. In addition, DIV1 had the most toxic effect on mammals, birds, fish, daphnia, algae, aquatic plants, earthworms, and bees (ecotoxicity load). The fate load of the pesticides used for the four systems was relatively similar, with DIV2 and DIV3 having the lowest averages (less pesticides for more crops). The pesticide load of the RS was the highest, indicating that the pesticides used for this system were the most dangerous in terms of quantity and toxicity (Figure 3).

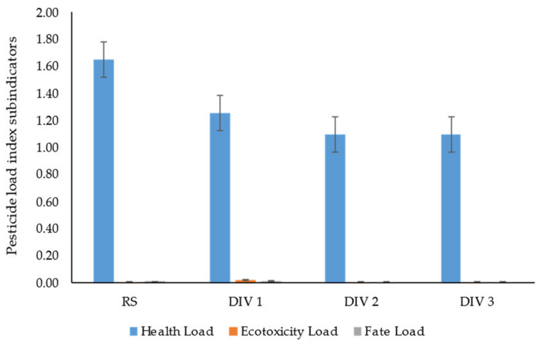

Figure 3. Average pesticide-load sub-indicators per system health load, ecotoxicity load, and fate load.

There was a 67% increase in total costs in DIV1, a 55% increase in DIV2, and a 32% increase in DIV3 compared with the reference system (RS). In addition, there was a 71% increase in income with DIV3, followed by a 48% increase with DIV2 and a 28% increase with DIV1 compared to the reference system (Figure 4).

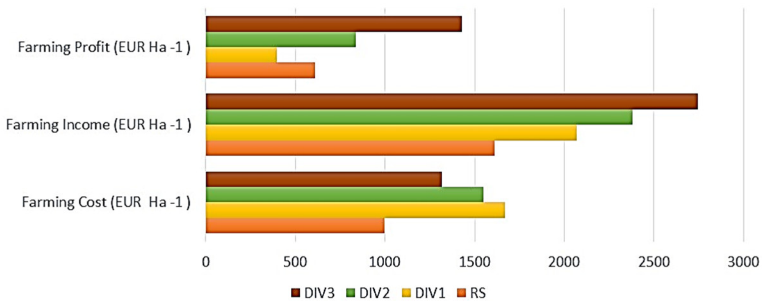

Figure 4. Economic indices of the four systems that were assessed.

4. Discussion

Based on the results, when legumes are incorporated in the cropping system, the result is that we have better environmental indices and higher farming profits. Similar results were reported in other studies, where the inclusion of legumes reduced the inputs and decreased the environmental impact of cropping systems [6,8]. However, the data are limited to Mediterranean cropping systems.

5. Conclusions

The four cropping systems that were evaluated gave interesting data that can be used to design more sustainable cropping systems. DIV3 is a system with low energy inputs and high outputs, significantly increasing the energy efficiency. Also, the same system has better economic and environmental indices than the other three systems, promising a sustainable cropping system for the Mediterranean areas.

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