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Editorial

Integrated Pest Management of Field Crops

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1. Introduction

The Special Issue "Integrated Pest Management of Field Crops" contains eight original research articles and two review articles dealing with different aspects of IPM in some of the major field crops, including Potato [1,2], Maize [2,3], Soybean [4], Sugar Beet [5], Barley [6], Rice [7], Eggplant [8] and Quinoa [9] as well as farmer education issues on IPM [10]. The papers published in the Special Issue address all eight principles of IPM, as proposed by Barzman et al. [11].

2. Principle 1: Prevention and Suppression

The first principle of IPM is the prevention and suppression of pests. The goal of IPM is not to eliminate pests completely, but to prevent a single pest from becoming dominant or causing damage in a cropping system [11]. This principle combines three different sub-principles [11]: combinations of tactics and multi-pest approach, crop rotation and crop management, and ecology. Each of these principles is discussed in the papers in this Special Issue.

A good example of the combination of tactics and multi-pest approach is the work of Poggi et al. [2], who discussed strategies to control wireworms in field crops. New agroecological strategies should start with a risk assessment based on the production context (e.g., crop, climate, soil characteristics and landscape) and monitoring of adult and/or larval populations. Suggested prophylactic measures to reduce wireworm infestation (e.g., low-risk crop rotations, tillage, and irrigation) should be applied when the risk of damage appears significant. They also suggested cures based on natural enemies and naturally derived insecticides, which are either under development or already practiced in some countries. It is interesting to note the suggestion that wireworm control practices do not necessarily need to target the pest population, but rather to reduce crop damage via the use of selected cropping practices (e.g., resistant varieties, planting and harvest timing) or by influencing wireworm behavior (e.g., companion plants).

Host plant resistance is an important strategy to prevent pest emergence and it is suggested for use in the control of several pests [11]. In a study by Raeyat et al. [8], the susceptibility of fourteen eggplant cultivars to green peach aphid (*Myzus persicae* Schultz) was investigated. The degree of antixenosis and anthibiosis was determined using different parameters. The authors identified three eggplant cultivars resistant to *M. persicae*. Susceptible cultivars were also identified. The authors proposed a plant resistance index (PRI) as a simplified method to evaluate all resistance mechanisms. It provides a certain value to determine the correct resistant cultivar.

Many cropping practices have a significant impact on pest incidence and susceptibility of cropping systems to pests. The ability of a crop to resist or tolerate pests and diseases is often related to optimal physical, chemical, and especially biological properties of the soil. In the work of Vahamidis et al. [6], different aspects of the epidemiology of net blotch disease (NFNB) caused by *Pyrenophora teres f. teres* and barley leaf scorch caused by *Rhynchosporium secalis* were investigated in an area free of barley diseases when the initial inoculation of the field occurred with the use of infected seeds. The study determined

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the spatial dynamics of disease spread under the interaction of the nitrogen rate and genotype in the presence of limited sources of infected host residue in the soil and the relationship between nitrogen rate, grain yield, quality variables (i.e., grain protein content and grain size), and disease severity. It was confirmed that both NFNB and leaf scorch can be transmitted from one season to the next in infected seed under Mediterranean conditions. However, disease severity was more pronounced after the barley tillering stage when the soil had been successfully inoculated, supporting the hypothesis that the major source of primary inoculum for NFNB is from infected host residues. An increase in the nitrogen application rate when malt barley was grown in the same field for the second consecutive year resulted in a nonsignificant increase in disease severity for both pathogens from anthesis. However, hotspot and commonality analyses indicated that spatial and genotypic effects were mainly responsible for hiding this effect. In addition, the effects of disease infection on yield, grain size, and grain protein content were found to vary with genotype, pathogen, and plant developmental stage. The importance of crop residues in the development of both diseases was also highlighted.

Biological balance refers to the interactions between organisms, including the structure of food webs and the ability of ecological systems to sustain themselves over time. Improper and inappropriate tillage can lead to increased soil compaction or disruption of the continuity of larger soil pores as well as corridors of soil organisms, and can affect the abundance, as well as the diversity of the biological component of the soil [12]. Lemić et al. [4] investigated the effects of different pre-sowing measures on the abundance and composition of total soil fauna in soybean cultivation, with special attention to carabids as biological indicators of agroecosystem quality. During the study, 7836 individuals of soil fauna were collected, out of which 84% were beneficial insects (insects or spiders). The number of fauna collected was influenced by the interaction between pre-sowing intervention and sampling date. Pre-sowing interventions that did not involve soil activities (such as cover crops, glyphosate application and mulching) did not affect the number and composition of soil fauna at the beginning of vegetation. Mechanical intervention in the soil and warmer and drier weather had a negative effect on soil fauna numbers and composition. As the season progresses, the influence of pre-sowing activities on soil fauna in soybean crops decreased. It appears that a reduction in mechanical activities in the shallow seed layer of the soil has a positive effect on species richness and diversity. The results of this study contributed significantly to a better understanding of the baseline situation of soil fauna in an intensive agricultural landscape and could be a good starting point for future studies and conservation programs.

3. Principle 2 and 3: Monitoring and Decision Based on Monitoring and Thresholds

Principle 2 (monitoring) and Principle 3 (decision making) come into play once the cropping system is established [11]. They are based on the idea that in-season control measures are the result of a sound decision-making process that takes into account actual or predicted pest occurrence. Weather and agronomic conditions in different areas can significantly affect the abundance of pests and their potential to cause damage to the same crop. Therefore, the life cycle of a species and its occurrence in newly developed areas may differ from those in areas where the crop has been grown for a long time. Studies on the biology and ecology of major pest species and their natural enemies are necessary to develop appropriate pest-management strategies for the crop. The study by Cruces et al. [9] investigated the incidence of insect pests and the natural enemies of quinoa in a traditional cultivation area, San Lorenzo (in the Andes), and in two new areas at lower altitudes, La Molina (on the coast) and Majes (in the Maritime Yunga ecoregion). Their data indicated that pest pressure in quinoa is higher at lower elevations than in the highlands. Non-traditional quinoa-growing areas have better conditions to produce higher yields than the Andean region. Pests are likely to become an important constraint to successful quinoa production, and the situation may worsen if pesticides are misapplied. The pest management strategies used in the three regions differ. The results suggest that agricultural extension programmes are still needed to improve the use of agrochemicals.

4. Principle 4: Non-Chemical Methods

Combining control measures in management strategies leads to more effective and sustainable results in the implementation of IPM [11]. The preference for non-chemical over chemical methods when they provide satisfactory pest control is defined as the fourth principle of IPM [11]. A wide range of non-chemical but direct measures are available for pest control. Some examples are soil solarization, trap cultivation, mechanical control, biological control or various biotechnical methods. However, their availability, effectiveness or usefulness varies greatly.

For example, Goldel et al. [1] list a wide range of alternative control methods used to date to control the Colorado potato beetle (*Leptinotarsa decemlineata* Say), the world's largest potato pest. In addition, they categorize the advantages and disadvantages of each method and compare them to conventional insecticides. They also discuss the positive and negative impacts of using alternative control methods and illustrate how alternative control methods, farmer activities, and environmental factors (e.g., biodiversity and ecosystem health) are closely linked in a cycle of self-reinforcing effects. Specifically, the higher the farmer adoption of alternative control methods, the healthier the ecosystem, including the biodiversity of pest enemies. The subsequent decrease in pest density potentially increases yield, profit, and farmer acceptance in using less conventional and more alternative methods.

Even though several non-chemical control methods are available for the most important pests, research and extension need to continuously develop more methods and tools. Once developed, they need to be integrated into pest-control strategies. Trap cropping as a method of controlling the new invasive nematode *Meloidogyne graminicola* (Golden and Birchfield) was studied by Sacchi et al. [7]. This is one of the most damaging organisms in rice crops worldwide and was first detected in mainland Europe (northern Italy) in 2016. Preliminary research results showed that nematode density and root gall index were lower in plots where rice was grown in three separate cycles and plants were destroyed at the second leaf stage each time compared to the other two management approaches. In addition, plant population density and rice plant growth were higher than in the unmanaged and control plots. Based on the studies, the use of the trap crop technique to control *M. graminicola* could be advocated for as a new pest management measure to control this pest in rice growing areas.

5. Principle 5 and 6: Pesticide Selection and Reduced Pesticide Use

Two principles of IPM directly target pesticides and suggest that the pesticides used should be as specific as possible to the target pests and have the least side effects on human health, non-target organisms and the environment. In addition, reducing the dosage, frequency of application, and resorting to the partial application of pesticides contributes to the goal of IPM to reduce or minimize risks to human health and the environment. Therefore, seed treatment has been considered as an ecologically acceptable method. Due to their negative effect on the environment (especially on bees, other pollinators and possibly on other non-target organisms), the use of neonicotinoid seed treatment insecticides is restricted. The studies conducted by Virić et al. [5] aimed to determine the residue levels of imidacloprid and thiamethoxam used for the seed treatment of sugar beet plants in different agroclimatic regions to assess the environmental risk and possible transfer to other crops. The study shows that imidacloprid and thiamethoxam used for seed treatment of sugar beet during sugar beet vegetation degraded below the maximum residue level allowed. Residue levels were highly dependent on weather conditions, especially rainfall. The results of this study show that seed treatment of sugar beet leads to a minimal trace in the plants as it is completely degraded by the end of the growing season, while higher residue concentrations in the soil show that there is a risk in dry climates or after a dry period.

Dry conditions, the inability to leach, or irregular flushing may result in higher concentrations in the soil, which may pose a potential risk to subsequent crops. This study provides additional arguments for a possible risk assessment in the seed treatment of sugar beet.

6. Principle 7: Anti-Resistance Strategies

Cases of pest resistance have been reported ever since man began using chemicals to protect plants. When a pest becomes resistant, the insecticide is used more frequently and eventually must be replaced as its effectiveness wanes. In their work, Kadoić Balaško et al. [3] attempted to find a reliable pattern of differences in resistance type in western corn rootworm (*Diabrotica virgifera virgifera* LeConte) using population genetic and geometric morphometric approaches. Their results confirmed that the hindwings of WCR contain valuable genetic information. This study highlights the ability of geometric morphometrics to detect genetic patterns and provides a reliable and cost-effective alternative for a preliminary estimation of population structure. The combined use of SNPs and geometric morphometrics to detect resistant variants is a novel approach in which morphological traits can provide additional information about underlying population genetics and morphology can contain useful information about genetic structure. The study provides new insights into an important and topical area of pest management, namely, of how to prevent or delay the evolution of pests into resistant populations to minimize the negative effects of resistance.

7. Principle 8: Evaluation

Principle 8 encourages farmers to evaluate the soundness of the crop protection measures they adopt [11]. This is a very important aspect of sound management. However, farmers' knowledge of pests and their understanding of pest management solutions is often very limited. Therefore, many researchers highlight the need for the continuous professional development of farmers, not only to provide administrative support, but also to provide advice on sustainable practices [13]. This is very important as climate change and the acceleration of global trade will increase uncertainties and the frequency of the occurrence of existing and new pests. The study by Houngbo et al. [10] investigated farmers' knowledge of *Spodoptera frugiperda* (J.E. Smith), their perceptions and their management practices in Benin. Their results showed that farmers' management practices were significantly related to their knowledge of the pest and their socio-economic characteristics such as membership of a farmers' organization and contact with research or extension services. Since farmer organizations and extension services have the potential to improve farmers' knowledge and bring about behavioral changes in their pest management strategies, they can influence the pest management decisions made by farmers. Therefore, extension services should consider disseminating relevant information in local languages and conducting demonstrations directly in fields to improve farmers' pest management knowledge and skills and their ability to assess the soundness of the pest management measures they adopt.

8. Conclusions

Field crops occupy about 1.7 billion hectares. They are at great risk of infestation by insects and diseases, so the amount of pesticides used in production is very high. One solution to reduce the use of pesticides is to implement IPM as a dynamic and flexible approach that takes into account the diversity of agricultural situations and the complexity of agroecosystems, which can improve the resilience of cropping systems and a farmer's ability to adapt crop protection to local conditions. The studies published in this Special Issue refer to all the basic principles of IPM as systemized by Barzman et al. [11] and provide examples of their implementation in different crops and cropping systems. Research on various aspects of the implementation of IPM in crop production is a continuous need. The research presented helps to provide a mosaic picture with examples of how crop-specific, site-specific and knowledge-intensive IPM practices should be considered and translated into workable practices.

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