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RESEARCH ARTICLE

Attempts for undoing the ecological incompatibility of agricultural technologies: from ecological pest management to agroecology

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Abstract **–** Current agroecology is often categorized into three facets, science, practice, and movement. While the latter two aspects currently play significant and varying roles in different regions of the world, the fundamental aspect is the first one, the scientific approach that subsequently provided the possibility of the birth of the other two. The concept of integrated plant protection i.e., the emphasis on ecological considerations in chemical pest control emerged as a revolutionary novel concept in the middle of the last century. Among the priority principles, there are several similarities between ecological plant protection suggested by the pioneering Hungarian researcher Barnabás Nagy in 1957 and integrated pest management (IPM) initiated by US scientists Stern *et al.* in 1959, in given aspects such as the use of natural enemies, forecasting, and environmentally friendly strategies. In turn, the principles of ecological plant protection and IPM overlap on numerous points, but differences are also apparent. Neither of these strategies, however, emphasize with due vigor the significance of persistence, pesticide residues, and chronic health-damaging effects. By today, properly assessing the environmental fate, behavior and chronic side effects of pesticides have become as important as taking the rapidly changing composition of local communities into consideration by the above three aspects of agroecology. The current pesticide re-registration strategy of the European Union focuses on prolonged changes from chronic effects. Ecological plant protection and IPM set preferences of sustainability e.g., the use of mechanical or biological protection methods and lowering the rate of agrochemical protection, but they have failed to establish transparent sustainability requirements that are easy to comprehend by general consumers. In contrast, ecological (organic) agriculture managed to formulate such clear regulations (a complete ban on synthetic pesticides), which is well-reflected in their rising preference by consumers but failed to prove that observed health benefits of organic produce is indeed due to the lack of the residues of those pesticides banned. In turn, the ecological approach currently has a strong presence in the form of the determined agroecological objectives of the European Green Deal. In retrospect, it is particularly impressive to observe the path of IPM, sustainable agriculture and all three aspects agroecology all rooted in the establishment of the ecological initiatives in the late fifties as their common historical scientific starting point.

Keywords – Barnabás Nagy, Vernon Stern, integrated pest management, biological pest control, organic farming, agroecology, pesticide, chronic effects, beneficial organisms, sustainability

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INTRODUCTION

In his pioneering study in 1957, Barnabás Nagy considered the contact/systemic characteristics of certain pesticide active ingredients, emphasized the importance of emerging pest resistance, highlighted commendable examples of the combined use of chemical and biological control methods, and called for a fully ecological approach to plant protection, as he clearly viewed the causes of the damage also as factors of ecological origin (Nagy, 1957). Independently from Nagy, yet two years later, in 1959, Stern and co-workers presented a more coherent view of the concept of the economic thresholds, provided a detailed explanation of the importance of microbiological plant protection agents of natural origin, expressed an optimistic view about selective active substances, and urged the integration of different control methods taking an important step from fundamental ecological aspects and practical examples of application towards agricultural plant protection technology development (Stern *et al.*, 1959). This latter approach, however, remained unsuccessful to date, as consumers are incapable to follow the differences in plant protection technologies, and thus, the combined use of pest control methods, although implemented in actual agricultural practices, has not resulted in a recognizable product category.

The article of Barnabás Nagy received substantial recognition and left a considerable mark on later research and development activities in Hungary, yet unfortunately, it is hardly cited in the international scientific literature, due to the mere fact that it was published in Hungarian in the journal *Növényvédelem* (the periodical at that time published under the name of *A növényvédelem időszerű kérdései*, which translates to English as *Current Issues in Plant Protection*). The very fact that the work was published only in Hungarian is the predominant factor why this epoch-making publication received such an inconsequential echo internationally, even though the article formulated important principles for ecotoxicology that emphasized the importance of coenological/ecological sciences in plant protection probably for the first time in the world. This article was a clear critique of the initial agrochemicals-based plant protection that has drawn legitimate and audible condemnation due to the use of chlorinated hydrocarbons (Carson, 1962; van den Bosch, 1987; Marco *et al.* 1987; Darvas, 2000). It preceded the work of Stern *et al.* on the principles of integrated pest management (IPM) by two years, and the landmark book of Rachel Carson pointing out on the basis of the impacts of persistent (agro)chemicals such as DDT and other chlorinated hydrocarbons, the astonishing weaknesses of chemical crop protection. It is certainly no coincidence that from the research group of Vernon Stern that led plant protection practice towards application only in justified cases by introducing the concept of the damage threshold, Robert van den Bosch published nearly a decade later his rightly famous book *The Pesticide Conspiracy* (van den Bosch, 1978). Van den Bosch perceived that the plant protection industry remained insufficiently attentive to the principles of IPM due to commercial reasons, simply because of counter-interests. As a professor at the University of California at Berkeley and head of the Rachel Carson Trust, he left a lasting mark on California's agriculture, which has perhaps resulted in the distinctive rigor regarding pesticide side-effects by the Pesticide Action Network (PAN, established in 1982, headquarter: San Francisco) and the California Environmental Protection Agency (Cal EPA, established in 1991, headquarter: Sacramento). It is most likely no coincidence either that Miguel Altieri also followed him as a professor at the University of California at Berkeley, learning the subsequent era of the concept of environmentally friendly plant protection (Altieri, 1987), giving rise also to the movement aspect of agroecology. Thus, the cumulative nature of knowledge and in parallel the impacts of outstanding scientific schools in the bloom of new concepts are markedly demonstrated in this scientific field as well.

The foundations laid down by Stern *et al.* were the basis of the thematic overview by Tibor Jermy, who published the principles of IPM in Hungarian, 18 years after the above-mentioned initial publication of Barnabás Nagy and referred mostly to the international literature (Jermy, 1975). Strangely, however, he failed to highlight the merits of Barnabás Nagy even though his survey was also published in Hungarian. At that time, most Hungarian researchers were captured by the isolation of the Hungarian language. In other words, even leading fundamental early works on ecology (termed biocoenoses or symbiology at that time) were published in Hungarian (Balogh, 1946), and the early concepts of plant protection based on coenology and ecology by Tibor Jermy, Barnabás Nagy, and Gusztáv Szelényi remained unrecognized in the international scientific literature due to the language barrier although they preceded corresponding knowledge published worldwide. In that era, the international language of science became English already, yet that active generation in the fifties in Hungary had completed their classical education in German as a primary foreign language (e.g., Szelényi, 1955; Jermy, 1956; 1958), and had been later forced, due to political-ideological reasons, to use Russian (e.g., Jermy, 1959), and publishing in English commenced only in the sixties (e.g., Jermy, 1961). Another linguistic bias of the era has been political: there existed a tangible demand towards scientist authors by the political regime to make reference to results of Soviet science. In his 1957 work, Nagy met this presumptive obligation of compulsory citation of Soviet scientists, and he managed to do it without any corruption in scientific merit. Both papers he referred to were studies well-recognized in the international scientific literature: one that appeared in 1950 in the Soviet periodical *Usp. Sovrem. Biol.* (*Успехи современной биологии*), meaning *Advances in Modern Biology* and to date reported in the PubMed database, and another that was published in 1953 in the periodical of VASHNIL, the Soviet Academy of Agricultural Sciences, named after V. I. Lenin. Both papers addressed the possibilities of biological crop protection, reflecting great ecological progressivity in the era of chemicalization of agriculture. To better appreciate conceptual achievement reflected by these studies, let us bear the political spirit of the era in mind, that just a few years before that VASHNIL declared to Generalissimus Stalin that all Soviet biologists accepted the principle of the inheritance of acquired characteristics (Lysenko, 1948; Anonymous, 1949), and that the President of VASHNIL at the time of the cited studies (during the periods of 1938-1956 and 1961-1962) was Trofim Denisovich Lysenko himself, father of the concept of acquired inheritance in the Soviet block and the midwife of the fall of agricultural productivity in the Soviet Union (Kolchinsky *et al.*, 2017). Lysenko's hypothesis gained such an immense political weight that Stalin personally edited Lysenko's text for the August 1948 session of VASHNIL (Rossianov, 1993). Another rather interesting political detail in Nagy's references to Russian scientists is that he mentions the pioneering work in locust control research by Boris Petrovich Uvarov (1888-1970), a Russian emigrant entomologist-ecologist of the British Museum, but not by specifying the exact source (Uvarov, 1947), only by referring to a study published in the German periodical *Zeitschrift für Angewandte Entomologie* (*Journal of Applied Entomology*) that cites Uvarov. The reason behind such indirect citation most also have been political: the fact that Uvarov escaped Russia after the communist revolution (a "dissident" – which was the term those days for emigrants to the West from behind the Iron Curtain) was to such an extent "unforgivable" to the political regime that direct acknowledgement of his work could not be allowed even though it appeared in the world's leading scientific periodical, *Nature* (London). It can even be considered bravery and fixation true scientific values by Nagy that he dared to place such a hidden mention of the eminent and decorated Russian-British scientist, Uvarov.

Barnabás Nagy and his colleagues viewed chemical plant protection with very skeptical eyes, expressing their early criticism. This is markedly expressed in the 1957 study by Nagy, being considered a pioneering work in retrospect, yet it has not been regarded by contemporary scholars as a revolutionary act, even though it could have reached such a reputation had it received international recognition.

OPINIONS REGARDING THE PAPER BY NAGY (1957)

In retrospect, it is apparent that the ecological approach has emerged in the agrochemicals-based agricultural technology setup as an entirely transformed concept e.g., as a new paradigm in the sense of the scientific progress theory by Thomas Kuhn (Kuhn, 1962). It is common in the history of science that a given breakthrough, a new paradigm is somehow "in the air", and numerous scientists reach out in parallel to grab the same essence. Thus, a step of novel advancement may be the outcome of a previous approach by someone else yet based on new considerations. Nagy recalled in his memories of his 1957 article later by writing "… I regarded crop protection needs to be carried out entirely on a unique landscape ecological basis that extensively takes the local biological/ecological conditions into account. For this, I considered the agronomist blessed with an ecological vein, well-acquainted with the natural conditions at the cultivation area, almost becoming a scientist who can make a quick, optimized decision in this individual, often immediate, pest gradation cases, a must. Based on the above, the term «organic plant protection» perhaps no longer appears to be so revolutionary, even though it was (also) born in 1956."

Due to the language barrier, written and spoken opinions regarding the 1957 paper by Barnabás Nagy are also predominantly restricted to Hungarian sources. Nagy and Vajna (1973) are of the opinion regarding integrated (harmonious, ecological, complex) plant protection that it is not an independent method, but an up to date (therefore, continuously changing with our acquired knowledge) approach. László Vajna has also stated that integrated pest management is nothing more than protection according to the common sense of a biologically trained farmer (Vajna, L. personal communication).

According to Darvas (1986), "with ecological plant protection, as he [Nagy] terms it, by emphasizing the use of a biological approach in chemical pest control, Nagy (1957) practically arrives to the formulation of integrated pest management according to Stern *et al.* (1959)". According to Darvas, the terminology mentioned is applied, in fact, in a technological sense, in which the methods of biological control take precedence over other possible solutions.

In Sáringer's (2008) wording, "Barnabás Nagy proposed an ecological control method against plant pests in 1957, which aimed to minimize the chemical control used in agrobiocoenoses […] As ecological and integrated control cover the same concept, this novel approach with a new point of view should be associated with the name of Barnabás Nagy all over the world". As explained earlier, we are of the opinion that the same result has not been accidentally achieved in parallel by several people. Nonetheless, perceptible differences also exist between the two descriptions.

A COMPARISON BETWEEN ECOLOGICAL PLANT PROTECTION (NAGY, 1957) AND INTEGRATED PEST MANAGEMENT (STERN *ET AL.*, 1959)

When comparing the two articles, it is immediately apparent that both papers cite mostly the same scientific literature in English. Therefore, it is not surprising that we find several overlaps between the key principles emphasized by the two papers. Natural enemies, forecasting, and environmentally friendly strategies (strip treatment, differences in pest sensitivities of varieties, etc.) are common ground. Stern *et al.* (1959) clarify their views on the concept of the economic damage threshold (immediate spraying upon pest emergence may not be necessary, tolerance is an important component), discuss in more detail the importance of microbial pesticides of natural origin (see *Bacillus thuringiensis*), and are more optimistic about the possibilities of selective insecticide agents. Nagy (1957) considers the contact/systemic nature of the active ingredients to be remarkable in sparing beneficial parasitoids and highlights pesticide resistance that Stern *et al.* (1959) mention with somewhat lesser emphasis. The latter authors, on the other hand, are pushing for the integration of different control methods, which, along with the concept of an economic damage threshold, is a move towards applicability and plant protection technologies.

Thus, the two strategies analyzed overlap in numerous respects, but the principles/control strategies of ecological plant protection are perhaps closer to biological plant protection (Darvas *et al.*, 1999; Darvas, 2011) (Figure 1) than to IPM, and their characteristics and possible consequences, although focusing on biological processes, and supplementing them with the use of chemical pesticides, are not sufficiently described. In our opinion, therefore, the principles of ecological pest management and IPM overlap in many respects, but the differences are also apparent from the descriptions.

Neither strategy considers with sufficient weight the consequences of the dissipation/persistence and the chronic health effects of the residues of the pesticide active ingredients and of other formulation constituents, and thus, assessments are stuck at the level of the acute toxicity solely of the active ingredient. It is, of course, unfair to express criticism after such a time perspective in retrospect, as neither the methods of environmental analytical chemistry were as advanced as today to allow sensitive detection of pesticide residues, nor the Rapid Alert System for Food and Feed (RASFF) database, established in 1979 and amended several times later (Commission of the European Communities, 1979; European Commission, 2002; 2011), existed at that time to record and report those residues in agricultural commodities. Moreover, toxicology at the time relied on the classical principles of Paracelsus, which are correct from the aspect of acute toxicity (accidental hazards) but do not necessarily apply to sublethal effects that lead to chronic health effects consequences. And leading problems in current toxicology are to be pinned down at these points. Moreover, exposure is as important of a toxicity criterion as dose. Currently, the environmental fate of plant protection products (water and soil and food contamination potential, effects on non-target organisms, in which pollinators play a key role), behavior (bioaccumulation, biomagnification), chronic side effects are at least as important as the rapidly changing composition of local food webs (Darvas and Székács, 2006). The current pesticide risk assessment of the re-registration procedures in the EU also includes the consideration of slow physiological changes that take place resulting from chronic effects (mutagenicity, carcinogenicity, teratogenicity, reproductive effects, hormonal, and immunomodulatory effects).

CROP PROTECTION STRATEGIES

Issues related to what we currently term sustainability that generated great controversy from the fifties were mainly debated by ecologists dealing with community ecology also in Hungary. The debate has initially been rather theoretical and scientific, and therefore, neither the strong advocacy of pesticide manufacturers nor the representation of agricultural producers (plant protection strategies) and consumers (recognizers of specific products) emerged yet as their aspects. The fact that the position of consumers became gradually more represented most certainly played a role in the public support for organic farming, and the key to its success has been the fact that it could define an easily distinguishable and communicable technology and products to the consumers (prohibition of the use of synthetic compounds and later a similar exclusion of GMOs from the production) along with strictly controlled and certified practices. The quality difference between these products and food containing pesticide residues was easily recognized, sometimes even overestimated by the consumers. At present, agriculture in the EU is moving in this direction, recognizing the fact that most of our current pesticides have been indicated to be mutagenic, and are suspected of exerting carcinogenicity or hormone-modulation (Darvas and Székács, 2006). Therefore, re-assessment of pesticides for such effects is ongoing, resulting in a rapid decline in the number of authorized active ingredients, regenerating problems in plant protection technologies, which is particularly critical for herbicides (Székács and Darvas, 2012; 2018; Székács, 2021). It has reached wide public recognition by now that environmental and human health has been severely affected by plant protection activities.

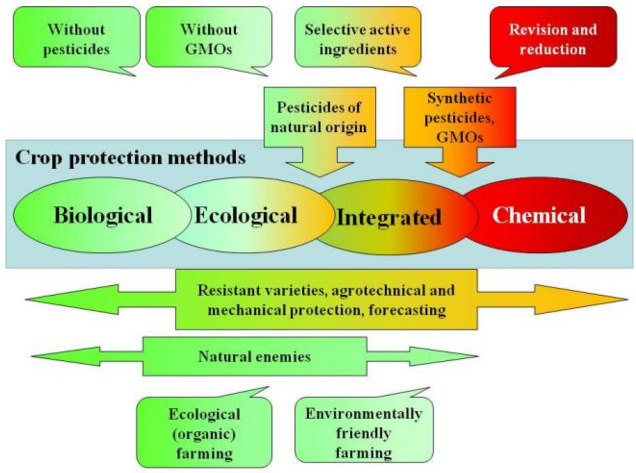

Figure 1. Crop protection strategies according to the biological, chemical, or combined (mixed) crop protection methods allowed in them. Agrochemicals-based technologies provide mass food products. Ecological (organic) farming provides commodities produced under inspected and certified processes without the use of synthetic pesticides or GMOs, recognized by a certain layer of consumers. Integrated farming (integrated pest management, IPM) utilizes biological crop protection, but also allows chemical pest control. The choice of chemical crop protection means is not transparently defined, therefore, the technology remained unrecognized and therefore not typically supported by the average consumer.

ECOLOGICAL PEST MANAGEMENT (EPM)

As seen above, the pioneering work by Nagy (1957) has laid down the principles of a pest control strategy that considers agriculture as an ecological system, the emergence of pests in it as a problem of ecological nature, and possible solutions for this problem also of fully ecological origin. Nagy himself attributed not much importance to this essay of his, he rather considered it as a statement of the obvious. Thus, he did not publish it in any foreign language, even though he addressed one of the key questions of theoretical plant protection of that time that remained valid to date. From the outlines of his notion with certain additional specifications, a technological concept we term ecological pest management (EPM) can be defined. The main difference between this concept and IPM is that the latter does not exclude chemical plant protection from its toolkit, only advises it as a low priority protection measure. EPM defines strict environmental restrictions for any agrochemicals applicable with high emphasis on their soil and water contamination potential to conserve soil and irrigation water quality, as well as to replenish soil organic matter.

We have proposed strict criteria for the selection of pesticides for EPM (Darvas and Székács, 2021) that considers the following environmental health parameters: (I) acute effects: (i) mammalian, (ii) avian, (iii) aquatic vertebrates (fishes, amphibians and reptiles), (iv) crustaceans, aquatic arthropods; (v) bees (honey bees and bumble bees), (vi) earthworms; (II) environmental chemical parameters: (vii) persistence (in soil and aquatic environments), (viii) water solubility and water pollution potential; (III) chronic toxicity: (ix) mutagenicity and genotoxicity, (x) carcinogenicity (according to IARC and US EPA classifications), (xi) reprotoxicity and teratogenicity, (xii) hormone modulating effects, (xiii) immunomodulatory effects, (xiv) mild effects on parasitoid arthropods, (xv) mild effects on predatory arthropods, (xvi) mild effects on algae. Numerous specific points of weakness remain in even such a strict system related to model species selection e.g., lack of adequate protection of amphibians, humus-forming arthropods, and soil-borne microorganisms. A recent comparative pesticide assessment also concluded that the ecotoxicological and environmental health status of currently used insecticides is outstandingly poor (Silva et al., 2022).

INTEGRATED PEST MANAGEMENT (IPM)

The initial definition for IPM by Stern *et al.* described IPM as a method of "applied pest control which combines and integrates biological and chemical control" (Stern *et al.*, 1959). Thus, the initial emphasis has been focused on the reduction of use of pesticides by proper timing of pesticide applications according to pest population levels and predefined economic thresholds; avoidance of the environmentally detrimental (e.g., harmful to human or environmental health, persistent) pesticide applications; and replacement/combination of agrochemicals with biological methods of protection. In fact, the EU Framework Directive 2009/128/EC on the sustainable use of pesticides and the Food and Agriculture Organization (FAO) of the United Nations to date defines integrated pest management as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human and animal health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms." (European Commission, 2009; Food and Agriculture Organization, 2017). Over time, the toolkit for IPM broadened, and the main characteristics of IPM have been categorized along with eight principles: (1) prevention and suppression, (2) monitoring, (3) decision based on monitoring and thresholds, (4) non-chemical methods of control, (5) pesticide selection, (6) reduced pesticide use, (7) anti-resistance strategies, and (8) evaluation (Barzman *et al.*, 2015; Bažok 2022). The concept of IPM tactics (Figure 2) indicates a hierarchy of practices, among which pesticides are listed only in case the alternative methods are insufficient. Indeed, a clear distinction among pesticides of natural origin (biopesticides, botanicals), biorational pesticides and the rest of synthetic pesticides is often made within IPM strategies. Initially classification within pesticides based on their IPM compatibility used to exits dividing authorized pesticide active ingredients into categories of allowed, questionable and restricted substances. With the increasing rigor of pesticide registration, however, this practice has faded. Pesticide use remains to be a controversial issue regarding their compatibility with IPM in several application types e.g., in the use of seed coatings or in genetically modified (GM) crops. Both examples are related to the requirement of pest control measures initiated only after the pest population exceeded the threshold level: neither preventive (prophylactic) pesticide use seed coating, nor the production of plant-expressed transgenic insecticidal endotoxins can be timed for the population dynamics of the pest(s) to be controlled. The active ingredient is released after planting the given cultivar in both application types throughout the vegetation period, regardless of the emergence of the pest. Moreover, as seen in Figure 2, preventive application of chemical pest control is excluded in IPM.

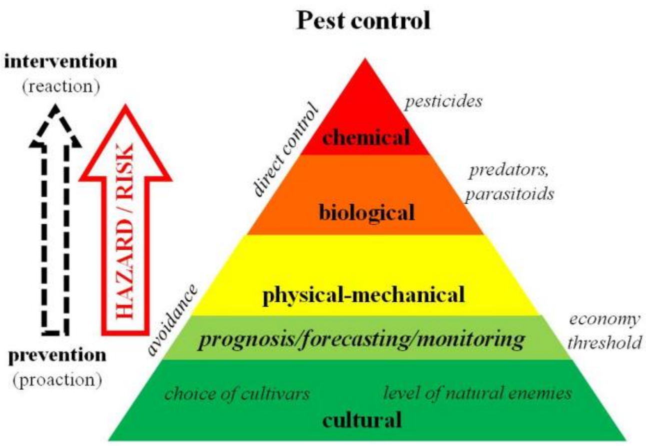

Figure 2. Pest control tactics in integrated pest management after US EPA (2021). The approach attempts to manage pests by applying a hierarchic set of "biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risks".

As seen, the concept of IPM introduced pronounced ecological considerations into crop protection strategies, yet it remained strongly technology-focused regarding the strong emphasis on the economy of pest control (economic injury level, economic threshold). The above FAO definition of IPM relies on the economic justification of pesticide use, and not pronouncedly on sustainability. The EU Framework Directive 2009/128/EC outlines several strict legal measures to achieve sustainable use of pesticides (above all the requirement of national action plans on pesticide use and the protection of the Natura 2000 biogeographical region sites), but otherwise formulated only intentions and not specific pesticide restrictions for IPM. In other words, the range of pesticides applicable under IPM remains the same that is governed by pesticide registration regulations for intensive agriculture, as the stringent regulatory requirements in pesticide registration are considered as a proper assurance for the sustainable use of the improved current pesticide products (Lykogianni *et al.*, 2021).

Currently, IPM-related scientific publications cover not only the above eight principles, but also diverse areas of agricultural technology development, ranging from the development of pesticides of natural origin, insect pheromone research, risk assessment of agricultural biotechnology, plant physiological and molecular biological responses to pathogen infection, rearing studies of beneficial organisms, pest recognition by remote sensing, and plant disease mapping, to studies of domestic animal-pastured cultivation of cultured plants, landscape ecology, yield optimization, and farmers' education. The majority of IPM approaches have been documented to be exerted (at least in the US) around rural and urban, primarily agricultural IPM (Young, 2017), yet the focus has broadened beyond agriculture, including issues of food security, management of invasive species, and climate change. Consequently, IPM corresponds to rather complex technological considerations that are hardly transparent to the laymen. The combinations of non-chemical (i.e., biological) methods among the means of plant protection and reduced pesticide use are easily comprehensible aims but understanding the other six objectives requires agrotechnical knowledge.

A particular problem in the economic model is that while benefits of IPM emerge at a societal level, the costs occur to the farmers, who have a right to undertake biocontrol but are not obliged to do so. Consequently, complex economy models are applied to harmonize costs and benefits using the so-called maximum incremental social tolerable irreversible costs as an evaluation tool (Benjamin and Wesseler, 2016). Economic viability remains an essential factor highly dependent on social acceptability, in which communication to the consumer is a key element (Dara, 2019). This could be facilitated by a, so far lacking, set of standardized and publicized international certification of IPM practices. IPM and biological control approaches are reported to have received sufficient attention through educational and dissemination/transfer activities to farmers to result in regime change and landscape influences (Giagnocavo *et al.*, 2022). In contrast, however, a multitude of IPM definitions and consequential confusion, as well as inconsistencies between IPM concepts, practice, and policies exist to date (Deguine *et al.* 2021).

Altogether, IPM as a specific technology has failed to become well-defined or remained unknown to the public, as consumers cannot keep track of differences in plant protection technologies. Thus, mixed-use (i.e., biological and chemical crop protection) has not yet resulted in any recognizable product. Thus, the concept of a product with integrated protection seems to remain only a blank official/producer slogan towards the consumers today. It may, of course, function in highly law-abiding societies such as Scandinavian countries, but only to a far lesser extent in less stringent ones.

Complementary agricultural financial subsidy measures in the European Union (EU) have been based on the use of IPM principles for a long time, while IPM is far not defined as a technology for specific cases and can be shaped into different forms and ranges according to individual farmers' practices (Benbrook *et al.*, 1996; Barzman *et al.*, 2015). While more and more strict (eco)toxicology requirements apply to current pesticide regulations, which is reflected in a decrease in the number of approved active ingredients in the EU and Hungary, particularly among insecticides (Darvas and Székács, 2021), problematic issues remain to exist. Regarding this, Darvas (2011) stated regarding the use of IPM principles in Hungary/Europe: "… I find it unacceptable to classify a technology as IPM if it uses water or soil polluting active ingredients that are toxic to pollinators or aquatic organisms. In my opinion, 70% of the pesticide active ingredients allowed to be used in IPM today do not comply with these criteria and therefore, there is an urgent need for a selection of pesticide active ingredients in the EU for this strategy, which is more stringent than the current general EU authorization. I hardly believe that the introduction of a brand indicating an integrated product and being recognized by conscious consumers would be possible based on the current practice. This would require significantly clearer and uncompromising content. I hardly believe that based on the current practice, it would be possible to introduce a brand that indicates an integrated product that will be rewarded by conscious consumers. This would require significantly more clearly defined and uncompromising content."

ECOLOGICAL (ORGANIC) AGRICULTURE

The holistic approach of IPM has been taken further in a concept of "ethical agriculture" (Altieri, 2012), taking sustainability as a main driver in ecological agriculture (also termed organic agriculture). The fundamental principles in ecological agriculture (not to be confused with ecological plant protection, see above) are health, ecology, fairness, and care, and the internationally accepted definition of ecological agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, considering that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system" (Food and Agriculture Organization, 1999).

Ecological agriculture has been indicated to provide a better balance than pesticide-based agriculture a combined assessment by productivity, environmental impact, economic viability, and social wellbeing (Reganold and Wachter, 2016), but at the cost of production yields, not only in amounts but also in variability (Reganold and Wachter, 2016; Meemken and Qaim, 2018; Smith et al., 2019). Ecological agriculture practices were indicated to strongly contribute to the increase of social welfare, the rational use of natural resources (water, land, and energy), the improvement of land cultivation and the mitigation of the emission of greenhouse gases and can play a substantial role in low-carbon agriculture and the development of bioeconomy (Cidón *et al.*, 2021). However, just like for IPM, environmental-economic modeling is also of high importance for ecological agriculture to assess incentives for conversion (Acs *et al.*, 2005), and it has been deemed questionable whether it could be profitable without external support (Meemken and Qaim, 2018).

As for the use of agrochemicals, ecological agriculture makes a clear self-definition by the overall bans of synthetic fertilizers, pesticides, and genetically modified organisms (GMOs). This is easily comprehensible to the general consumer, and therefore, it has gained increasing popularity among the environmentally aware public mostly in industrially developed countries. In addition, inspection and certification have been internationally developed, and ecological/organic produce and food have become a well-established market brand.

Nonetheless, the concept of the full avoidance of synthetic pesticides but approval of natural substances is not free of internal contradiction. The approach appears to consider natural origin as a warrant for environmental benignity – an obvious misapprehension. Moreover, it discriminates between a natural substance and the same molecule prepared synthetically. And in spite of the ban on synthetic substances, the pesticide- and GMO-free status of ecological agriculture may still be jeopardized by various agro environmental conditions, including (1) widespread environmental pesticide contamination; (2) possible effects of application of biocides for hygienic use; (3) assumed occurrence of natural organic microcontaminants (e.g. mycotoxins); and (4) parallel application of organic agricultural practices and genetically modified (GM) crops (Székács, 2013).

Improved nutritional status of ecological produce have been claimed (Hunter *et al.*, 2011), but doubts have also been cast on it (Smith-Spangler *et al.*, 2012; Mie *et al.*, 2017; Meemken and Qaim, 2018). Our own study on spice paprika cultivation demonstrated the effect of intensive pesticide treatment not only on the pesticide residue level occurring in the crop, but also in the deterioration of product composition at high pesticide application rates (Mörtl *et al.*, 2012). As pointed out recently, the fact that food from ecological agriculture would benefit human health through reduced exposure to pesticide residues has not been proven (Mesnage *et al.*, 2020). Favorable health statuses among organic food consumers have been indicated, and the lower levels of pesticide residues in organic than in non-organic food have been evidenced, yet the causative relationship between these two factors has not been verified. An additional internal controversy in considering the ban of synthetic substances as a key to health benefits is that the natural origin of substances allowed to be used in organic farming cannot be considered as a full guarantee to prevent environmental health concerns. The reduced pesticide use, however, is a clear environmental benefit.

AGROECOLOGY

The ecological approach is additionally gaining ground within the social and public policy approaches to agricultural practices. The use of plant protection products has now been evaluated from the point of view of sustainability, from which agroecology has also grown as a concept (Altieri, 1987; Salazar *et al.*, 2020; Székács *et al.*, 2020). Agroecology attempts to achieve true sustainability by incorporating ten elements in its approach: diversity, co-creation of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance, and circular and solidarity economy (FAO 2018; Barrios et al. 2020). Thus, agroecology takes a step further towards aiming for an ecological balance both biologically and societally. As Miguel A. Altieri explains: “Organic farming systems that do not challenge the monocultural nature of plantations and rely on external inputs as well as foreign and expensive certification seals, IPM systems that only reduce insecticide use while leaving the rest of the agrochemical package untouched, or fair-trade coffee systems destined only for agro-export, may in some cases benefit biodiversity, but in general offer very little to small farmers that become dependent on external inputs and foreign and volatile markets. … Agroecology provides the scientific basis and methodology to design biodiverse agroecosystems capable of sponsoring their own function.” (Altieri, 2012). Thus, agroecology, in addition to strongly representing global ecology and the environment as viewpoints, also stands for human, economic and social aspects. As an approach, it appears in social practice in a triple facet: science, practice and movement (Gliessman, 2020). On the one hand, it is an independent scientific discipline that deals with the study of life communities in agricultural areas i.e., it is a part of ecological sciences on the basis that has been discussed above related to the pioneering works of Nagy (1957) and Stern *et al.* (1959). On the other hand, it is an agricultural practice, in which the practical application of traditional farming knowledge combined with today's innovative solutions and the sustainable use of local renewable resources are emphasized. Thirdly, it is a social movement, typically organized from the bottom up, which, in addition to the above, specifically prioritizes the protection of family farms and small farms as well as rural communities, the use of landscape-specific species, the operation of local and short product chains, and the public right to food self-sufficiency. Barnabás Nagy's ecological approach can be considered the first forerunner of the ecological science nature of agroecology mentioned above (Székács *et al.*, 2020). Although such a scholarly approach in principle appears like a basic element – in an optimal case – also in the latter two trends (in farming practice and societal movement), nonetheless it weakens scientifically as it shifts towards the social movement and public policy aspects.

In addition, the ecological approach has a strong presence in the pronounced agro-ecological objectives of the European Green Agreement (European Commission, 2020), which aim to make Europe a climate-neutral continent by using circular resource management, restoring biodiversity, protecting the environment, among others by halving the use of pesticides by 2030 and implementing ecological (organic) farming on the quarter of the overall agricultural land in the EU by 2030. As a member of the EU, domestic policy agrees with these objectives but considers them to be exaggerated and currently unachievable conditions that could jeopardize the competitiveness of European agriculture, reduce the number of farmers and lead to higher food prices. Looking back, however, we can see the process as a consistent development of the sector (science and agricultural practice), the historical starting point of which laid, among others, the formulation of the ecological approaches by Nagy and Stern *et al.*

CONCLUSIONS

Ecological plant protection and IPM have common roots in the pioneering works by Nagy (1957) and Stern et al. (1959). The strong emphasis on ecological considerations in agricultural practices promoted sustainability but eventually gave birth to two radically different approaches. IPM developed into an immensely complex approach, hardly comprehensible in full even by trained professionals. In turn, it offers multifarious solutions, but lacks a uniform definition and has not resulted in a clear product category on the market. In contrast to IPM, ecological agriculture clearly defines itself at the technological level with the complete exclusion of synthetic pesticides, fertilizers, and GMOs, resulting in sustainability advantages but lacking proof that health benefits would, indeed, result from the pesticide-free status. Agroecology represents the ecology principle as a scientific discipline, an agricultural practice, and a social movement to give rise to biodiverse agroecosystems and just societal circumstances.

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