SUMARRY

of the doctoral thesis entitled:

OPTIMIZATION OF SOME ORGANIC VEGETABLE CROP SYSTEMS USING ALLELOPATHIC INTERACTIONS

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Allelopathy is a natural process through which certain plants, bacteria, algae, and fungi produce chemical compounds that influence the growth and development of other organisms in their environment. Allelopathy can be integrated into vegetable cropping systems through crop rotations, intercropping, cover crops, green manures, mulching, and the use of extracts derived from allelopathic species.

The application of allelopathy in weed control requires further research, as it is a naturally occurring process that evolves over time, similar to how weeds adapt and evolve for survival. This contrasts with synthetic herbicides, which are standardized but can lead to the development of resistance in plant species. In organic farming systems, it is imperative to identify and implement innovative control methods, considering that climate change accelerates weed evolution, placing increasing pressure on crops. Some of the most aggressive weed species utilize allelopathy as an efficient survival strategy, allowing them to outcompete other plants. Given this adaptability, allelopathy should be further explored as a promising method to support sustainable and ecological agriculture.

Since allelopathy is a complex phenomenon influenced by multiple biotic and abiotic factors, extensive research is needed to develop strategies for its practical and economically viable application in vegetable production and beyond. Research on allelopathic interactions contributes to the development of environmentally sustainable agricultural techniques that are also advantageous from a socio-economic perspective. Integrating allelopathy through various mechanisms into vegetable cropping systems can serve as an effective strategy for controlling weeds, diseases, and pests.

The interaction between weeds and vegetable crops causes substantial economic losses for farmers. Firstly, it reduces both the quality and quantity of the yield. Secondly, it increases production costs due to the need for labor and herbicides to control weeds.

Allelopathic compounds generally exhibit low or no toxicity to beneficial animals and insects, possess diverse modes of action, and have relatively high degradation rates.

The aim of this doctoral thesis is to evaluate the potential application of allelopathy in weed control within organic vegetable cropping systems.

In these circumstances, the thesis aims to conduct experiments and scientific research to optimize technologies that integrate allelopathic species into climbing bean (*Phaseolus vulgaris*) and long pepper (*Capsicum annuum* convar. *longum*) cropping systems. The research objectives will be addressed through a well-defined sequence of stages, each playing a specific role in achieving the overall goal. These objectives focus on developing solutions to improve technologies incorporating allelopathic species for weed management in vegetable cropping systems. To achieve this goal, the following objectives have been defined:

• ***Objective 1:*** Study of allelopathic extracts and soil interactions;

• ***Objective 2:*** Evaluation of weed control in organic vegetable cropping systems using allelopathic interactions;

• ***Objective 3:*** Assessment of yield quantity and quality in organic vegetable cropping systems using allelopathic interactions;

• ***Objective 4:*** Evaluation of disease and pest control in organic vegetable cropping systems using allelopathic interactions.

The doctoral thesis, ***"Optimization of organic vegetable cropping systems using allelopathic interactions,"*** is structured into two parts, comprising a total of seven chapters, 58 tables, 66 figures, and 215 bibliographic references.

The first part of the thesis is dedicated to the literature review on the research topic and is structured into two chapters. It explores the importance of using allelopathy for weed control, defines allelopathic relationships in the context of organic agriculture, and highlights plant species with allelopathic potential.

The second part of the thesis presents the original research conducted over four years of study and is organized into five chapters. These chapters detail the methodology used, the experiments performed, the results obtained, the analysis and interpretation of data, as well as the relevant conclusions for optimizing technologies that incorporate allelopathic species in weed control within climbing bean and long pepper cropping systems.

In ***Chapter 1,*** titled ***The importance of using allelopathy in organic vegetable crops***, fundamental aspects of the allelopathic phenomenon are addressed, including the definition of allelopathic relationships in the context of organic agriculture, the mechanisms of action underlying this process, the use of allelopathy as a strategy for weed management in vegetable cropping systems, the influence of environmental factors and genotype on allelopathy, as well as the interaction between allelopathy and interspecies competition.

In ***Chapter 2,*** titled ***Plant species with allelopathic potential***, plant species with allelopathic properties used in vegetable cropping systems are analyzed. For each identified species, a detailed review was conducted regarding the allelopathic compounds present and their effects on weed control. The studied species include red clover (*Trifolium pratense*), white clover (*Trifolium repens*), barley (*Hordeum vulgare*), two-row barley (*Hordeum distichon*), oat (*Avena sativa*), bird's-foot trefoil (*Lotus corniculatus*), sainfoin (*Onobrychis viciifolia*), oil radish (*Raphanus sativus* var. *oleiformis*), yellow mustard (*Sinapis alba*), and Japanese lawn grass (*Lolium perenne*, *Festuca rubra*, *Poa pratensis*).

Additionally, the chapter examines crops protected through allelopathic means, analyzing their sensitivity to weed interactions and their response to minimal soil tillage. The study focuses on climbing bean, a representative of the *Fabaceae* family, and long pepper, belonging to the *Solanaceae* family, highlighting their adaptation strategies within sustainable vegetable cropping systems with minimal soil intervention.

Chapter 3, entitled ***The Purpose and Objectives of the Thesis, Materials and General Methodology, and General Framework Conditions***, presents the objectives and experimental approach of the research.

The main aim of the study is to evaluate the potential application of allelopathy for weed control in organic vegetable crops. In this context, the research is directed toward four specific objectives. To achieve these objectives, the chapter details the biological material used and the experimental methodology applied. It describes the organization of the research for climbing bean and long pepper crops, as well as the specific procedures corresponding to each objective. These include soil analysis, germination tests using allelopathic extracts, evaluation of weed control efficiency, assessment of crop yield, and the impact on plant health.

The experiments were conducted between 2022 and 2024 in an experimental field of the Vegetable Research and Development Station Bacău (VRDS), within a series of trials involving climbing bean and long pepper crop under organic farming conditions.

The biological material used and the work methodology for climbing bean crop are presented below.

The biological material consisted of 11 plant species with potential allelopathic properties: red clover, white clover, sainfoin, oil radish, white mustard, barley, two-row barley, oats, perennial ryegrass, red fescue, and Kentucky bluegrass. A single experimental factor was studied, mixtures of species with allelopathic potential sown in an intercropping system with the climbing bean cultivar "Auria Bacăului". The experiments were arranged in randomized blocks with three replications. For the bean crop, 20 planting hills (3–4 seeds per hill) were sown per replication, with a spacing of 30 cm between hills in the row. The hills were arranged in parallel rows, grouped in 0.4 m-wide strips spaced 2.2 m apart.

Six experimental variants (including a control) were used (V1: red clover + climbing bean; V2: red clover, white clover, sainfoin + climbing bean; V3: red clover, Japanese lawn mix + climbing bean; V4: red clover, mustard, oil radish + climbing bean; V5: red clover, barley, two-row barley, oats, sainfoin + climbing bean; V6: control – manually and mechanically weeded climbing bean monoculture.

Each variant was replicated three times, resulting in a total of 18 experimental plots with a combined area of 118.8 m^2.

The allelopathic plant variants were mowed twice, and the resulting biomass was left on the soil surface. When weather conditions favored excessive weed growth, hoeing was recommended around the bean plants to reduce competition and ensure optimal growth conditions. The control plots were mechanically weeded twice between the rows and manually weeded twice within the rows.

The climbing bean crop was fertilized once using ORGEVIT (1–1.5 t/ha), Biochar (250 kg/ha), and Bionat (0.2–0.8%/L).

The biological material used and the work methodology for long pepper crop are presented below.

The biological material consisted of long pepper plants and two plant species with allelopathic potential: white clover (*Trifolium repens*) and bird's-foot trefoil (*Lotus corniculatus*). These species were cultivated in an intercropping system with the long pepper cultivar "Ionel."

The experimental factor studied was the mixture of species with allelopathic properties, sown in an intercropping system with the pepper crop. The pepper crop was established using seedlings. The seedlings were produced in plug trays. Seeds were sown in seedling trays and kept in a controlled environment, after which the seedlings were transplanted into plug trays. The pepper seedlings were transplanted into the field on May 11. The mixture of allelopathic species was sown on March 20.

The experiment was organized in randomized blocks. Each replicate plot included 162 plants, with a spacing of 17–19 cm between plants and 70 cm between rows. Two experimental variants (including the control) were used, arranged in three replications, resulting in a total of six replicated plots, with a total experimental area of 155.57 m^2.

The variant with allelopathic species was mowed three times, while the control plot was weeded three times.

The pepper crop was fertilized with ORGEVIT (1–1.5 t/ha), Biochar (250 kg/ha), and Bionat (0.2–0.8%/L).

Chapter 3 also presents the materials and methodology used for studying the influence of allelopathic interactions on the environment and crop development.

The biological material used for the study of the influence of allelopathic plants on the soil is the same as in the previous experiment.

Soil analysis was conducted on samples collected from the research field at the Vegetable Research and Development Station (VRDS) Bacău, within the experiment carried out on the climbing bean crop. For each soil sample, the following characteristics were determined:

- Soil pH, to evaluate the soil's reaction and its impact on nutrient solubility;
- Humus content, as an indicator of the amount of available organic matter, essential for maintaining adequate biological activity in the soil;
- Corrected phosphorus (corrected P), to measure the availability of phosphorus to plants, adjusted according to the soil characteristics;
- Potassium (K), to assess the availability of this essential nutrient for plant development.

The biological material used and the working methodology for the study of the influence of extracts on seed germination are as follows.

Allelopathic extract testing was conducted separately on perennial ryegrass seeds, using plant species with allelopathic potential collected from the bean field experiment (white clover, red clover, white mustard, oil radish, barley, two-row barley, and oats). Five plant-based extracts were studied, each subjected to a dilution process to obtain three different concentrations: 10%, 25%, and 50%, as follows (V1a – white clover extract at 10% concentration; V1b – white clover extract at 25% concentration; V1c – white clover extract at 50% concentration; V2a – red clover extract at 10% concentration; V2b – red clover extract at 25% concentration; V2c – red clover extract at 50% concentration; V3a – white mustard extract at 10% concentration; V3b – white mustard extract at 25% concentration; V3c – white mustard extract at 50% concentration; V4a – oil radish extract at 10% concentration; V4b – oil radish extract at 25% concentration; V4c – oil radish extract at 50% concentration; V5a – barley, two-row barley, and oat extract at 10% concentration; V5b – barley, two-row barley, and oat extract at 25% concentration; V5c – barley, two-row barley, and oat extract at 50% concentration; V6 – control, treated with distilled water.

The germination tests were performed to evaluate the effects of the extracts on seeds, with the following parameters measured: Final germination percentage (FGP), Inhibition rate (IR), Mean germination time (MGT), Germination rate index (GRI), First day of germination (FDG), Last day of germination (LDG), Mean root length, Mean hypocotyl length, Seedling vigor index (SVI).

Thus, the soil analysis and the testing of allelopathic extracts were treated as separate experiments, each with distinct objectives and methodologies, yet complementary in evaluating the allelopathic effects on the environment and plants.

The biological material used and the methodology for the study of the influence of allelopathic species on weed control are presented below.

Field research methods were employed to analyze the effectiveness of allelopathic interactions in weed suppression.

The main factors studied to achieve this objective included:

- Weed biomass, to evaluate the total amount of vegetative material produced by weeds;
- Weed density, to determine the number of weed plants per unit area;
- Weed infestation degree, to measure the intensity of weed occurrence and spread;

- Weed height, to observe the growth of weed species and the potential effects of allelopathic interactions on their development;
- Weed phenophase, to monitor the developmental stages and the sensitivity of weed species to allelopathic influences at different growth stages;
- Weed species composition, to evaluate the diversity of weed flora and how it is affected by allelopathic factors.

The biological material used and the methodology for the study of the influence of allelopathic species on the quantity and quality of the yield are presented below.

Both field and laboratory research methods were employed to analyze the impact of allelopathic interactions on crop production and quality.

The main factors studied to achieve this objective included:

- Yield (bean seeds, pepper fruits), to assess the productivity of the crop in relation to allelopathic effects;
- Anthocyanin and chlorophyll content, to analyze the levels of bioactive compounds and plant pigments essential for plant health;
- Soluble solid content, as an indicator of fruit ripeness and overall crop quality, determined by refractometry in the laboratory;
- Number of pods per plant (beans) / number of flowers per plant (peppers), to evaluate plant fertility and production potential, measured directly in the field;
- β-carotene and lycopene content in the pepper crop;
- Plant height (peppers), as a measure of vegetative development and the plant's response to environmental and allelopathic conditions;
- Root length and weight, to observe the development of the root system and its effects on plant nutrition, assessed through both direct field measurements and laboratory weight analyses.

These studies were conducted through both field observations and laboratory analyses in order to evaluate the impact of allelopathy on production and quality indicators in organic bean and pepper cropping systems.

The biological material used and the working methodology for the study of the influence of allelopathic species on diseases and pests will be presented below.

Field research methods were used to analyze the effectiveness of allelopathic relationships in controlling diseases and pests. Periodic observations were carried out in the crops to monitor the phytosanitary status.

To achieve this objective, the following main factors were studied:

- Frequency (F%);
- Intensity (I%);
- Degree of attack (Gr%).

Additionally, the chapter includes a characterization of the natural conditions of the experimental area, addressing aspects such as geographical location, soil characteristics, agroclimatic and meteorological conditions throughout the entire study period.

Chapter 4, titled ***Results on the influence of allelopathic species on soil and seed germination,*** presents the findings of research concerning the impact of allelopathic species on soil characteristics and the germination process.

The analyzed data reveal a variable influence of allelopathic species on soil parameters, with significant differences observed in terms of pH, humus content, and phosphorus availability. The allelopathic species showed a positive effect on humus stability and on the controlled mobilization of phosphorus, thereby contributing to the maintenance of soil fertility. Although their impact on soil pH was relatively minor, these species played an important role in soil protection and in stimulating mineralization and humification processes, suggesting long-term benefits for bean cultivation under slightly alkaline conditions.

Regarding the germination of perennial ryegrass seeds, extracts from white clover, red clover, mustard, barley, two-row barley, and oats showed an increasingly inhibitory effect as their concentrations increased. Among these, the extract combination of barley, two-row barley, and oats exhibited the strongest inhibitory effect, leading to a significant reduction in germination at higher concentrations. In contrast, the extract of oil radish had minimal impact on germination, behaving similarly to the distilled water control, even at high concentrations. These results suggest that certain plant extracts can significantly influence seed germination, while others exert less pronounced effects.

Chapter 5, titled ***Results regarding the influence of allelopathic species in climbing garden bean crop,*** presents the outcomes of evaluations regarding weed control, yield quality and quantity, as well as crop protection.

The results related to weed control indicate that the use of allelopathic species was effective in reducing both weed density and biomass. ANOVA analysis revealed statistically significant differences between the experimental variants, showing that certain allelopathic species combinations, such as V4 (red clover, mustard, oil radish – beans) and V5 (red clover, barley, two-row barley, oats, sainfoin – beans), had a marked effect on reducing weed populations across the three years of experimentation. These combinations demonstrated high efficacy compared to the mechanically weeded control. Moreover, it was observed that certain problematic species such as cockspur (*Echinochloa crus-galli*) and red-root amaranth (*Amaranthus retroflexus*) maintained high densities throughout the three assessment stages, while others were better controlled through the use of allelopathic plants.

The use of allelopathic species did not negatively affect key physiological parameters of the crop, such as chlorophyll content, anthocyanin levels, or soluble solid content. Furthermore, bean yield was not adversely impacted; in fact, certain allelopathic combinations contributed to improved root architecture, suggesting a favorable influence on the plant growth environment.

With respect to crop protection, no significant attacks from diseases or pests were recorded. The most frequently observed diseases were rust (*Uromyces appendiculatus*), bacterial blight (*Xanthomonas campestris* p.v. *phaseoli*), anthracnose (*Colletotrichum lindemuthianum*), and common bean mosaic virus (BCMV). Among the pests, the most relevant were aphids (*Aphis fabae*), fruit borer (*Helicoverpa armigera*), two-spotted spider mite (*Tetranychus urticae*), and occasionally stink bugs (*Nezara viridula*). Overall, the use of allelopathic species did not have a negative effect on the protection of climbing bean crops, and their influence on the control of diseases and pests was largely neutral.

Chapter 6, titled ***Results regarding the influence of allelopathic species in long pepper crop,*** presents the findings obtained following the evaluation of the impact of allelopathic species on weed control, crop yield and quality, as well as on the protection of cultivated plants.

In the pepper crop, the use of allelopathic species demonstrated significant efficacy in weed suppression. The variant that included white clover (*Trifolium repens*) and bird's-foot trefoil (*Lotus corniculatus*) exhibited a clear inhibitory effect on weed growth compared to the control, consistently across the three analyzed years. The analysis of identified weed species revealed that red-root amaranth (*Amaranthus retroflexus*), field bindweed (*Convolvulus arvensis*), purslane (*Portulaca oleracea*), cockspur (*Echinochloa crus-galli*), and gallant soldier (*Galinsoga parviflora*) were the most frequently occurring.

The variant incorporating allelopathic species had a significant impact on the development of pepper plants, as evidenced by notable increases in chlorophyll and anthocyanin pigment content. However, no statistically significant differences were recorded regarding the number of flowers per plant, fruit weight, or fruit length and width. Concerning yield, significant differences were observed between variants in the years 2022 and 2024, with the control treatment producing higher yields. In light of these findings, it is essential to develop strategies to optimize growing conditions in order to reduce yield disparities among the experimental variants and enhance overall productivity.

Regarding plant protection in the pepper crop, diseases and pests were present at low levels. The main diseases observed were blossom-end rot, and more rarely, pepper late blight (*Phytophthora capsici*) and early blight (*Alternaria solani*). The identified pests included the leaf miner fly (*Liriomyza trifolii*), the fruit borer (*Helicoverpa armigera*), and aphids (*Aphidoidea* sp.). Additionally, the natural presence of ladybugs (*Coccinella* spp.) was recorded in the pepper crop, acting as predators for aphid populations, thereby highlighting the ecological complexity of predator-prey relationships within these agroecosystems.

In ***Chapter 7,*** titled ***General conclusions and recommendations,*** the final conclusions related to the research objectives are presented.

Regarding the evaluation of weed control in organic vegetable crop systems using allelopathic interactions, it was found that allelopathic species demonstrated effectiveness in controlling weeds both in the bean crop and the pepper crop. The effectiveness of control was influenced by factors such as sowing date, climatic conditions, and the type of allelopathic species used.

Concerning the study of allelopathic extracts and their influence on soil, a variable effect of allelopathic species on soil parameters was observed, with significant differences in pH, humus content, and phosphorus levels. Allelopathic species had a positive impact on humus stability and the controlled mobilization of phosphorus, contributing to maintaining soil fertility. It is necessary to extend these studies over the long term to observe the effects on the soil.

Regarding the germination of perennial ryegrass seeds, extracts from white clover, red clover, mustard, barley, two-row barley, and oats showed a more pronounced inhibitory effect at higher concentrations. Among these, extracts of barley, two-row barley, and oats had the most significant inhibitory effect, leading to a considerable reduction in germination. In contrast, the extract of oil radish had minimal impact on perennial ryegrass germination, comparable to the control, even at higher concentrations.

In terms of evaluating the quality and quantity of the harvest in organic vegetable crop systems using allelopathic interactions, the use of allelopathic species in climbing bean crops did not negatively affect the qualitative and quantitative parameters of the plants. The findings suggest that allelopathic species may positively influence the growth environment of the plants, especially by improving root architecture. Although no significant effects on yield were observed, there was a decrease in total production, production per plant, and pod count between 2022 and 2024. This trend can be explained by adverse climatic conditions, such as drought and high temperatures in 2024.

Regarding the pepper crop, allelopathic species had a positive effect on fruit quality and the root system; however, in terms of yield, a decrease was observed in two of the three years analyzed.

In relation to evaluating disease and pest control in organic vegetable crop systems using allelopathic interactions, no significant issues were reported in either the climbing bean or the pepper crops. However, long-term studies are necessary to analyze the positive or negative effects of allelopathic species on disease and pest control.