Effects of Insect Frass on Growth and Weed Occurrence in Chamomile (*Matricaria chamomilla* L.)

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Summary

The research was carried out in 2023 in a field experiment in Kosovo to determine the impact of fertilizers (insect frass and artificial fertilizer) on the occurrence of weeds and the growth of chamomile. During the growing season, weed recordings per 1 m² were carried out twice, in April and May. In the experiment, a total of eight treatments were studied: Three treatments with different amounts of frass fertilization (feces from *Tenebrio molitor* L. 1758), two with combined frass and NPK 15-15-15 and KAN-27% and one with NPK 15-15-15, and two controls without fertilization, but without and with wooden dust mulching. The dominant weed species of chamomile were *Capsella bursa-pastoris* (L.) Medik., *Plantago lanceolata* L., *Myosotis arvensis* L., and *Aphanes arvensis* L. The smallest number of weeds was recorded in plots where frass was used: 1 $t \cdot ha^{-1}$ + KAN-27%-500 $kg \cdot ha^{-1}$, with 12.6 $plants \cdot m^{-2}$. In the plots where frass was used (1 $t \cdot ha^{-1}$ + NPK 15-15-15-450 kg $\cdot ha^{-1}$), the number of weeds was higher, with 17.8 $plants \cdot m^{-2}$. The combined treatment of frass at 1 $t \cdot ha^{-1}$ and NPK at 15:15:15–450 $kg \cdot ha^{-1}$ achieved higher fresh biomass of chamomile at 3.475 $g \cdot m^{-2}$, and frass at a dose of 5 $t \cdot ha^{-1}$ had the highest impact at 2.700 $g \cdot m^{-2}$. Plants in the treatment with frass 1 $t \cdot ha^{-1}$ and NPK 15-15-15 had average heights of 89.3 cm, while plants in the control treatment had smaller average heights of 52.5 cm. For soil nutrients, there were differences found between the treatments, but the significant differences were for N (%), P_2O_5, K_2O, Mn, and Soil Organic Matter (SOM%).

Key words

organic fertiliser, medicinal aromatic plant, weeds, Kosovo

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Introduction

The production of medicinal aromatic plants (MAPs) has expanded in Kosovo in recent years. In total 16 different species of MAPs are grown in Kosovo, where 1.282 hectares of MAPs have been planted, with a total production of 808 t (Organika, 2020). Chamomile is cultivated in a total area of 550 ha (Organika, 2000), and the chamomile production is mainly located in the Dukagjini Plain, which is characterized by more favorable climatic and soil conditions. However, research related to the use of insect frass and occurrence of weeds in the cultivation of MAPs is missing in Kosovo, except for research on the flora of weeds in MAPs in the locality of Vitia conducted by (Sahiti, 2022) and on oregano in Istog (Isufi, 2023). Insect frass is considered an organic fertilizer (Ortiz et al., 2016). Insect frass, such as mealworm frass produced by the mealworm (*Tenebrio molitor* L. 1758), is an efficient natural fertilizer. Due to its rapid mineralization and the presence of nutrients in an easily available form, it serves as a source of nitrogen, phosphorus and potassium (NPK). This enhances biomass and nutrient content in barley, primarily by stimulating soil microbial activity (Houben et al., 2020). Mealworm frass with an NPK balance of 3-2-2 ($g \cdot 100\ g^{-1}$) and an iron content of 140 $mg \cdot kg^{-1}$, potted, can affect grain growth, increase leaf chlorophyll content, length of stem, stem width, and fresh biomass (Poveda et al., 2019). The accumulation of frass in the soil has a great impact on soil fertility due to the high content of nutrients and the content of C (Frost and Hunter, 2004; Lovett and Ruesink, 1995).

Insect frass, derived from mass-reared insects, is increasingly recognized for its potential as an organic fertilizer in sustainable agriculture (Poveda, 2021). Frass contains significant levels of essential nutrients, including nitrogen, phosphorus and potassium (NPK), as well as micronutrients like copper and zinc, making it comparable to or even superior to traditional organic fertilizers such as farmyard manure (Houben et al., 2020). Its composition also includes chitin, a biopolymer from insect exoskeletons, which not only conditions the soil but also activates plant immune responses, enhancing resistance to pests and diseases through priming and the activation of defense-related genes (Blakstad, 2021; Ahmad et al., 2024).

Unlike synthetic fertilizers, which can lead to soil degradation and environmental pollution, frass is biodegradable and supports soil microbial activity (Praeg et al., 2023; Poveda, 2021). Frass has also been found to stimulate soil microbial activity more significantly than synthetic fertilizers, which is attributed to its high organic matter content that enhances microbial biomass and metabolic activity (Houben et al., 2020). Additionally, frass releases nutrients more gradually than synthetic fertilizers, which may limit its immediate effectiveness in high-demand scenarios but supports long-term soil fertility (Houben et al., 2020).

Moreover, frass reduces environmental risks compared to synthetic fertilizers by releasing water-soluble phosphorus at a rate five times lower, thus minimizing phosphorus leaching and soil sorption issues (Houben et al., 2020). This characteristic highlights its potential as a more sustainable alternative for nutrient management in agriculture. However, the nutrient composition and efficacy of frass can vary significantly depending on the insect species and their diet, leading to inconsistencies in its application (Praeg et al., 2023).

In recent times, the frass from the insect species *Hermetia illucens* L. 1758 has also been used to fertilize plants (Elisen et al., 2023). Due to the high nutritional content and microorganisms of interest in agriculture, the use of insect frass as fertilizer can help limit the use of agrochemicals and contribute to the development of sustainable agriculture (Poveda, 2021). Today, there are several companies worldwide that trade in insect frass (Dicke, 2018; Payne et al., 2016).

The aim of the research was to analyze the occurrence of weed species in chamomile in the locality of Istog and determine the influence of frass on the growth and development of chamomile and content of soil nutrients.

Material and Methods

The field experiment was conducted in a chamomile field with a total area of 20 ha at an altitude of 470 m above sea level in the Istog municipality of Kosovo in 2023 (Figs. 1 and 2.). According to the IUSS Working Group WRB (2006), the soil type where the research was conducted was Cambisol District. During 2023, the temperatures were high and the precipitation was lower than in average years (Table 1).

Figure 1. Use of frass in chamomile

Table 1. Mean air temperature (°C) and rainfall (mm) in Istog in 2023

2023	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Tmax (ºC)	12.8	18.7	23.2	21.2	25.9	33.2	36.7	35.4	31.8	27.4	21.6	20.8	25.7
Tmin (ºC)	-4.0	-9.5	-3.9	-3.1	4.3	10.3	10.5	7.7	9.4	4.0	-3.4	-5.0	1.5
T average (ºC)	3.5	3.5	8.0	9.6	15.5	19.2	23.7	22.4	20.6	14.5	7.7	3.9	12.7
Rainfall	151	27	52	72.3	47.2	105	37.1	6.6	0.5	3.5	67.8	46	616.4

Source: Hydrometeorological Institute of Kosovo (HMIK)

The experiment was arranged according to the randomized block design with four replications, and the elementary plot size was 15 m^2 (5.0 length x 3.0 width). In the experiment, there were eight treatments, six fertilizer treatments (frass in different doses, in combination with NPK 15-15-15 and KAN 27%, and NPK 15-15-15 alone) and two control treatments but without and with wooden hull mulching (Table 2). The frass was produced by GoBeyond LLC (Limited Liability Company, a start-up, research-based company located in Prishtina, Kosovo). In all treatments, the insect frass was not sterilized.

Figure 2. Cultivation of chamomile

Table 2. Basic data for the application of frass, NPK 15-15-15 and KAN-27%

Treatments	Product	t/kg/ha
A	Frass	5
B	Frass	3
C	Frass	2
D	Frass + KAN-27%	1 + 500
E	Frass + NPK 15-15-15	1+ 450
F	NPK 15-15-15	450
G	Wooden dust	0
H	Control	0

Note: A-C: frass; D: frass + KAN 27%; E: frass + NPK 15-15-15; F: NPK 15-15-15; G: mulching; H: control

The mealworms were reared on by-products of local agricultural processing, primarily wheat bran, as their main feed. Carrots were used as a water source, and rearing conditions were maintained at a temperature of 27 °C with 70% relative humidity. The frass was used in its original, untreated form for experimental purposes and was applied manually to the experimental plots, ensuring even distribution across the designated treatment areas (Fig. 1).

The chemical content of used frass, based on analyses reported by Raiffeisen Laborservice, shows a pH of 5.83. The macroelements include 3.47% total nitrogen (N), 3.38% phosphorus (P_2O_5) and 2.5% potassium (K_2O). The content of microelements amounted to 1.02% magnesium (Mg), 0.29% calcium (Ca), 0.022% manganese (Mn), 0.05% sodium oxide (Na_2O) and 0.012% zinc (Zn).

Chamomile, the cultivar German chamomile was planted in rows of 15–25 cm between plants and within rows. During the cultivation, all agronomic measures such as ploughing, tillage and other necessary treatments for the cultivation of chamomile were applied (Šilješ et al., 1992). The weeds were recorded based on quantitative and qualitative methods for 1 m^2 in the centre of each 15 m^2 plot twice during the vegetation in April and May. The height of the plants (10 plants/plot) and the aboveground fresh biomass of chamomile for 1 m^2 were measured at the end of the vegetation period.

Atlases and plant keys were used for the determination of weeds (Mehmeti et. al., 2015; Demiri, 1979), while life forms (growth habits and environmental preferences of plants) were determined according to Ellenberg et al. (1992).

At the end of the experiment, soil samples were taken according to the ISO 11074-2-1998 method. Then, soil analyses were performed to analyze the pH ($CaCl_2/H_2O$) according to the ISO 10390-2004 method. In addition, organic matter was analyzed according to the combustion loss method for macroelements and microelements. Phosphorus and potassium were determined by the method of extraction with ammonium lactate (AL), according to Egner and Riehm (1995). All chemical analyses were performed in the soil laboratory at the Faculty of Agriculture and Veterinary, University of Prishtina.

Classification of soils for suitability of P_2O_5 and K_2O content according to the Egnér et al. (1960) was given in mg/100 gr and was presented as <10 very low, 10-15 low, 15-20 medium, and >25 high. Nitrogen was calculated as its content in organic matter is 5% (Wells et al., 1997). The suitability of other elements was determined by extracting the samples with ammonium acetate 1N. The extracts were analyzed by ICP OES (Shimadzu, ICPE-9820).

Statistical Analysis

The data were analysed using Analysis of Variance (ANOVA). The independent variables of frass and artificial fertilizers were used in different doses to test their effect on the response variables above fresh biomass, height of chamomile and soil nutrients. Significant differences were tested using the Tukey HSD test. The ANOVA was undertaken in statistical computer programme SAS Institute Inc. (2012).

Results and Discussion

A total of 14 weed species were recorded, which is considered a relatively poor diversity of weed species (Table 3). A similar number of weed species in chamomile was reported previously in Egypt and Poland (Hendawy et al., 2019; Kwiatkowski et al., 2020). In contrast, Negaso et al. (2022) found high species numbers of weeds in chamomile in Ehtiopia. In general, the number of weed species occurring in cropped fields depends on the agricultural practices applied over a longer period and the resulting weed species composition in the respective soil seed bank (Thompson et al., 2008).

The registered weeds belong to 11 families, while the dominant species were from the *Fabaceae, Plantaginaceae,* and *Poaceae* families with two species each, while the other families were represented by one species each. The dominant weed species were *C. bursa-pastoris*, *P. lanceolata*, *M. arvensis*, and *A. arvensis*.

In plots treated with frass and artificial fertilizers, there were differences in the number of weed species compared to the control. The smallest number of weeds was recorded in plots where frass was used in the amount of 1.0 t·ha^{-1} + KAN-27%, with 12.6 weeds/m^2, and plots with wooden dust without fertilization that had 10.2 weeds/m^2. In plots treated with NPK 15-15-15-450 kg·ha^{-1}, the number of weeds was higher compared to all other treatments (ie. 17.8 weeds/m^2).

However, it is notable that in the plots where a combination of artificial fertilizers frass 1 t·ha^{-1} + NPK15:15:15-450 kg·ha^{-1} were used, the number of weeds was also high (15.0 individuals·m^{-2}), while in the control plot without wooden dust 14.3 individuals·m^{-2} were recorded. These results are congruent with Isufi (2023), where the highest number of weeds found was in plots treated with NPK 15-15-15 in oregano.

As for the number of weeds in the plots treated with frass, it ranged from 13.5 weeds·m^{-2} in plots treated with 2 t·ha^{-1} to 16.3 weeds·m^{-2} in plots treated with 5.0 t·ha^{-1}. In plots where 5 t·ha^{-1} of frass were used, the dominant weeds were *C. bursa-pastoris* (7.3 plants·m^{-2}), *P. lanceolata* (3.9 plants·m^{-2}), and *M. arvensis* and *A. arvensis* (1.4 plants·m^{-2}), respectively. In the plot where 3 t·ha^{-1} of frass were used, the same species occurred, but with different numbers of weeds: *C. bursa-pastoris* (5.9 plants·m^{-2}), *P. lanceolata* (3.3 plants·m^{-2}), and *M. arvensis* (1.3 plants·m^{-2}), while in the plot where 2 t·ha^{-1} of frass were used, *C. bursa-pastoris* (5.6 plants·m^{-2}), *P. lanceolata* (4.4 plants·m^{-2}), and *M. arvensis* (1.7 plants·m^{-2}) dominated. In the last plot where 1.0 t·ha^{-1} frass and KAN-27%–500 kg·ha^{-1} were used, the only two dominant species were *C. bursa-pastoris* (5.9 plants·m^{-2}) and *P. lanceolata* (2.9 plants·m^{-2}).

In the plot where the combination of artificial fertilizers with frass 1 t·ha^{-1} + NPK 15-15-15-450 kg·ha^{-1} was used, almost the same species dominated as in the plots with frass but with a different number of weeds. The dominant species were *C. bursa-pastoris* (5.3 plants·m^{-2}), *M. arvensis* (3.4 plants·m^{-2}), and *P. lanceolata* (2.5 plants·m^{-2}), while in the plots where artificial fertilizer NPK 15-15-15-450 kg·ha^{-1} was used, *C. bursa-pastoris* (4.8 plants·m^{-2}), *P. lanceolata* (4.5 plants·m^{-2}), *M. arvensis* (3.0 plants·m^{-2}), and *A. arvensis* (1.8 plants·m^{-2}) were dominant.

In the plot where mulching with wooden hull was applied, the dominant species were *C. bursa-pastoris* (4.1 plants·m^{-2}), *P. lanceolata* (2.4 plants·m^{-2}), and *A. arvensis* (1.8 plants·m^{-2}).

There were significant differences between plots fertilized with frass and artificial fertilizer in terms of the number of certain dominant weed species (Table 3.). The average number of weeds per 1 m^2 is similar to Kwiatkowski et al. (2020), where the authors found that the number of weeds in chamomile ranged from 16.1-20.8 plants·m^{-2}.

The smallest number of weeds was in the plots with wooden dust, since mulching suppressed weeds (Joshi et al., 2021). Of the 14 recorded species of weed in chamomile, broad-leaved weeds dominated (85.7%), while there were only two species of grasses (14.3%). In terms of the dominance of broad-leaved grass species these results are consistent with the research conducted on the MAPs (Sahiti, 2022; Isufi, 2023). That is, broad-leaved species dominated with 84.5%, and grasses accounted for 15.5% (Sahiti, 2022), while 89.5% were broad-leaved species and 10.5% were grasses (Isufi, 2023). The perennial weeds were more widespread compared to annuals, but it is quite characteristic that perennial weeds were also notably widespread. This likely results from the application of mechanical measures for the control of weeds in the past on the plot where the research was carried out. However, annual weeds dominated with 64.3%, followed by perennials with 35.7%. These results are consistent with Sahiti (2022), who reported that in MAPs, annual weeds dominated (51.2%), though perennials were present (48.8%).

Table 3. The occurrence of weeds, species life forms of weeds and average number of weeds in chamomile cultivation in locality of Istog.

Life forms	Weed species	Treatments							
		A	B	C	D	E	F	G	H
T	*Agrostemma githago* L.	0	0	0.1	0.5	0.3	0	0	0
T	*Aphanes arvensis* L.	1.4^{a}	0.6^{b}	0.7^{b}	0.7^{b}	0.4^{b}	1.8^{a}	1.8^{a}	1.7^{a}
T	*Capsella bursa pastoris* L.	7.3^{a}	5.9^{ab}	5.6^{ab}	5.9^{ab}	5.3^{ab}	4.8^{ab}	4.1^{b}	5.3^{ab}
T	*Centaurea cyanus* L.	0	0.1	0	0	0.1	0.3	0	0
H	*Convolvulus arvensis* L.	0.9	0	0.4	0.3	0.3	0.6	0	0.7
T, H	*Erodium cicutarium* L. L'Her.	0.3	0	0	0	0	0.3	0.3	0.1
T, H	*Lamium puprureum* L.	0	0	0	0.1	0	0	0	0
H	*Plantago lanceolata* L.	3.9^{abc}	3.4^{ab}	4.4^{a}	2.9^{abc}	2.5^{bc}	4.5^{a}	2.4^{c}	4.0^{abc}
H, C	*Poa trivialis* L.	0	0	0	0.3	1.4	0.7	0	0
H	*Sorghum halepense* (L.) Pers.	0.3	1.2	0	0	0.9	1.0	0.6	0.1
C, H	*Trifolium repens* L.	0.5	0.4	0	0	0.1	0.1	0.1	0
T, H	*Myosotis arvensis* (L.) Hill.	1.4^{cd}	1.3^{cd}	1.7^{bcd}	0.9^{d}	3.4^{a}	3.0^{ab}	0.9^{d}	2.3^{abc}
T	*Veronica persica* Poir.	0	0.6	0	0	0.3	0	0	0
T	*Vicia angustifolia* L.	0.3	0.4	0.6	0.7	0	0.7	0	0.1
Number of weeds/m^2		16.3	13.9	13.5	12.6	15.0	17.8	10.2	14.3
Number of weed species/m^2		9.0	9.0	7.0	9.0	11.0	11.0	7.0	8.0

Note: T - *Therophytes*, H - *Hemicryptophytes*, H - *Hygrophytes*, C - *Chamaephytes*
A-C: Frass; D: Frass + KAN 27%; E: Frass + NPK 15-15-15; F: NPK 15-15-15; G: wooden dust; H: control; values within same row marked with different letters are significantly different (Tukey's HSD test, $P < 0.05$)

Of the 14 weed species found in chamomile, therophyte weeds dominated with 53.6%, not a very high percentage compared to hemicryptophytes at 39.3%. Meanwhile, the group of camephytes had a lower percentage of 7.1%. These results for the biological spectrum of weeds agree with Sahiti (2022), who reported that therophytes dominated with 47%, then hemicryptophytes with 37%, geophytes with 10%, and the other groups were less present in MAPs.

The mealworm frass and the artificial fertilizers used in chamomile significantly impacted the above ground fresh biomass of chamomile ($F_{2,42} = 19.2$, $P < 0.0001$). The treatments where frass was used had an impact on the aboveground fresh biomass of chamomile compared to the control plot, but there were statistically significant differences only with treatments where frass was used with 5 t·ha^{-1} and combined 1 t·ha^{-1} frass with fertilizer NPK 15-15-15-450 kg·ha^{-1} (Fig. 3).

The combined treatment of frass 1 t·ha^{-1} and NPK 15-15-15-450 kg·ha^{-1} achieved the highest aboveground fresh biomass of chamomile (3.475 g/m²). Frass used alone at a dose of 5 t·ha^{-1} resulted in the second highest aboveground fresh biomass of chamomile (2.700 g/m²).

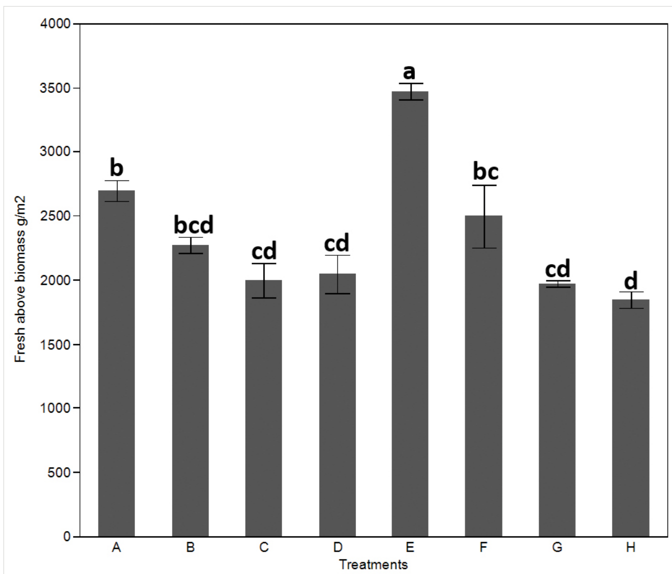

Figure 3. Impact of frass, NPK 15-15-15 and KAN-27% in above fresh biomass of chamomile (mean ± SD)

Note: A-C: frass; D: frass + NAG 27%; E: frass + NPK 15-15-15; F: NPK 15-15-15; G: mulching; H: control; values marked with different letters are significantly different (Tukey's HSD test, $P < 0.05$)

Additionally, NPK 15-15-15 (450 kg·ha^{-1}) also had an effect on the aboveground fresh biomass of chamomile, yielding 2.500 g/m².

As for the impact of frass and NPK, it has been studied that in laboratory conditions they also impact the biomass of barley (Houben et al., 2020) and spinach (Antoniadis et al., 2023), but it should be taken into account that the large amount of frass can also affect the reduction of the yield of some crops, such as green salad (Fuertes-Mendizábal, 2023).

The fertilizer consisting of mealworm frass but also the artificial fertilizers used in chamomile sigificantly impacted the height of chamomile ($F_{2,42}$ = 70.2, P < 0.0001).

Chamomile plant height was an average of 64.7 cm. The plants in the treatment where the combination of frass 1 t·ha^{-1} + NPK 15-15-15-450 kg·ha^{-1} was used, were the highest, on average (89.3 cm), while the plants in the control treatment had a smaller height on average (52.5 cm) (Fig. 4).

Statistically significant differences were found between the treatments where frass and artificial fertilizer were used and the treatments with mulching and control (Fig. 4).

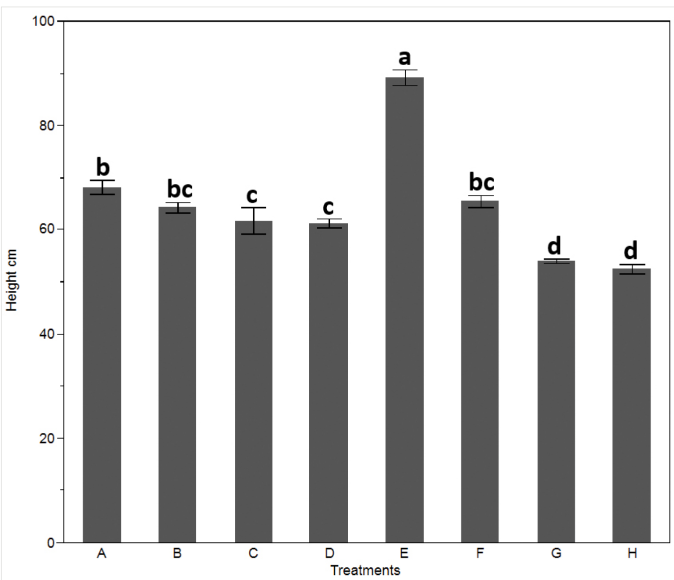

Figure 4. Impact of frass, NPK 15-15-15 and KAN-27% in height of chamomile (mean ±SD)

Note: A-C: frass; D: frass + NAG 27%; E: frass + NPK 15-15-15; F: NPK 15-15-15; G: mulching; H: control; values marked with different letters are significantly different (Tukey's HSD test, P < 0.05)

In treatments where frass was used at 5 t·ha^{-1}, the height of chamomile reached 68.2 cm, and there were significant differences among the treatments where frass was used at 2 t·ha^{-1} (61.8 cm) and 1 t·ha^{-1}+ KAN-27% 450 kg·ha (61.3 cm). However, it should be taken into consideration that the height of chamomile also depends on the cultivars of chamomile (Hendawy et al., 2015), and the type of material used for mulching (Joshi et al., 2021).

Others have also shown that depending on the doses of organic fertilizer and artificial fertilizer and their combination a slight increase in the height of chamomile is found (Prasad 2020). However, the amount of N used is of importance in the end height of chamomile, since according to research conducted by Alhasan et al. (2022), with the increase in the dose of N, the height of chamomile increases compared to the control plot.

In the plots where frass was used in amounts of 5 and 3 t·ha^{-1}, it was observed that a decrease in pH, H_2O, and $CaCl_2$ occurred if compared to the plots where NPK 15-15-15 and KAN-27% fertilizer were used. This can be explained by of the acidic nature of the frass (Houben, 2020).

In the plots where frass was used at 2, 3, and 5 t·ha^{-1}, the soil organic matter content was significanlty higher compared to other plots fertilized with NPK 15-15-15, KAN-27%, and combined frass at 1 t·ha^{-1}+ NPK 15-15-15 (Table 4). Studies have also demonstrated that frass works synergistically with synthetic fertilizers, combining the rapid nutrient availability of synthetic inputs with the soil health benefits of frass. This synergy enhances both nutrient uptake and microbial activity in soils, offering a balanced approach to improving crop productivity and sustainability (Houben et al., 2020; Ahmad et al., 2024). Comparatively, while chemical fertilizers supply nutrients quickly, they often contribute to soil degradation over time, whereas frass promotes sustainable soil health through its organic composition and nutrient release pattern (Houben et al., 2020; Ahmad et al., 2024).

The largest amount of N was detected in the plots where 2, 5, and 3 t·ha^{-1} frass were used. However, statistically significant differences were found among the plots where frass 2 and 5 t·ha^{-1} were used with the control plot and the plot where the combination frass 1 t·ha^{-1}+ KAN-27% was used ($F_{2.42}$ = 4.0, P < 0.0001).

There was a significant effect of frass on the P_2O_5 content. However, there were only significant differences between the plot where NPK 15-15-15 was used, the plot with mulching, and the control plot ($F_{2.42}$ = 6.7, P < 0.0001). Although there were no statistically significant differences among the other treatments, the highest amount of P_2O_5 mg·100 g^{-1} was in the plot where NPK 15-15-15 and the frass combination 1 t·ha^{-1}+ NPK 15-15-15 were used. The content extracted with ammonium acetate was also analyzed for other elements that were below the detection limit, such as Cd, Pb, Co, and Mo.

Soil analyses showed that the highest amount of K_2O was detected in the plots where NPK 15-15-15-450 kg·ha^{-1} was used and in the plot where the combination of frass 1 t·ha^{-1}+ KAN-27% was used.

However, when we compare the results in the plots where frass was used with 2, 3, and 5 t·ha^{-1} with the control plot, we notice a small difference that is not statistically significant (Table 4.). Statistically significant differences were found between the plot where NPK 15-15-15-450 kg·ha^{-1} and the plot where the combination of frass 1 t·ha^{-1}+ NPK 15-15-15 were used, compared to the control plot ($F_{2.42}$ = 32.2, P < 0.0001).

Table 4. Content of macro and microelements after the use of frass, NPK 15-15-15 and KAN-27% (mean ± SD)

Treatments	pH		(%)		mg/kg						
	H_2O	$CaCl_2$	MO	N	P_2O_5	K_2O	Ca	Mg	Mn	Na	Zn
A	$6.9^{a} \pm 0.07$	$5.9^{a} \pm 0.07$	$7.5^{a} \pm 1.4$	$0.36^{a} \pm 0.08$	$156.8^{ab} \pm 23.3$	$803.4^{c} \pm 128.6$	$676.8^{a} \pm 56.1$	$72.8^{a} \pm 2.6$	$20.8^{bc} \pm 1.8$	$89.1^{a} \pm 5.8$	$1.4^{a} \pm 0.12$
B	$6.9^{a} \pm 0.20$	$5.9^{a} \pm 0.15$	$7.1^{ab} \pm 0.92$	$0.37^{b} \pm 0.06$	$149.4^{ab} \pm 3.5$	$791.0^{c} \pm 34.9$	$573.0^{a} \pm 80.2$	$58.7^{a} \pm 8.7$	$19.2^{c} \pm 2.5$	$77.5^{a} \pm 19.2$	$1.1^{a} \pm 0.32$
C	$6.9^{a} \pm 0.08$	$6.1^{a} \pm 0.08$	$7.2^{ab} \pm 0.87$	$0.35^{a} \pm 0.05$	$145.5^{ab} \pm 35.6$	$801.9^{c} \pm 71.1$	$894.3^{a} \pm 257.1$	$63.4^{a} \pm 20.1$	$22.3^{abc} \pm 4.7$	$85.6^{a} \pm 31.8$	$1.1^{a} \pm 0.32$
D	$7.0^{a} \pm 0.11$	$6.0^{a} \pm 0.04$	$4.9^{b} \pm 0.90$	$0.24^{b} \pm 0.05$	$168.2^{a} \pm 11.2$	$1328.2^{b} \pm 49.2$	$645.0^{a} \pm 86.4$	$71.4^{a} \pm 14.5$	$19.3^{c} \pm 2.4$	$75.4^{a} \pm 4.1$	$1.7^{a} \pm 0.79$
E	$6.8^{a} \pm 0.18$	$5.9^{a} \pm 0.14$	$5.2^{ab} \pm 0.93$	$0.26^{ab} \pm 0.05$	$164.0^{a} \pm 10.6$	$898.3^{c} \pm 116.3$	$652.0^{a} \pm 22.9$	$75.6^{a} \pm 10.6$	31.5 ± 6.5a	$95.3^{a} \pm 48.8$	$1.1^{a} \pm 0.52$
F	$6.9^{a} \pm 0.26$	$6.1^{a} \pm 0.21$	$5.3^{ab} \pm 1.0$	$0.26^{ab} \pm 0.05$	$184.2^{a} \pm 2.6$	$1589.6^{a} \pm 236.3$	$699.5^{a} \pm 205.3$	$75.7^{a} \pm 15.6$	$28.9^{ab} \pm 4.3$	$104.5^{a} \pm 66.8$	$1.1^{a} \pm 0.15$
G	$7.3^{a} \pm 0.35$	$6.3^{a} \pm 0.40$	$5.9^{ab} \pm 0.95$	$0.29^{b} \pm 0.05$	$112.5^{b} \pm 29.1$	$761.3^{c} \pm 42.0$	$555.3^{a} \pm 93.7$	$61.3^{a} \pm 11.1$	$19.3^{c} \pm 0.9$	$76.6^{a} \pm 26.2$	$0.98^{a} \pm 1.12$
H	$6.8^{a} \pm 0.23$	$6.1^{a} \pm 0.13$	$5.1^{b} \pm 0.89$	$0.24^{b} \pm 0.05$	$112.7^{b} \pm 7.6$	$759.2^{c} \pm 69.3$	$625.0^{a} \pm 68.9$	$70.0^{a} \pm 6.4$	$18.4^{c} \pm 1.8.$	$54.3^{a} \pm 4.2$	$1.0^{a} \pm 0.12$

Note: A-C: Frass; D: Frass + KAN 27%; E: Frass + NPK 15-15-15; F: NPK 15-15-15; G: mulching; H: control; values within same column marked with different letters are significantly different (Tukey's HSD test, $P < 0.05$)

Conclusions

Recent innovative agricultural approaches, among others, aim to transform large amounts of organic waste and by-products into protein for animal feed and natural fertilizer insect frass using insects in the concept of vertical farming. This trend creates new opportunities for sustainable agriculture and the circular economy worldwide. Organic farmers face expensive imports of fertilizers and soil enhancers, and organic products are rare in Kosovo. With the increasing global crises, their availability will negatively impact the operations of small and medium-sized farms. The results show that frass, when produced and applied under certain conditions, has an effect on the fresh biomass, height of chamomile and soil nutrients. However, it should be considered that the effect of frass strongly depends on the insect species, diet (by-products as their main feed), type of soil and climatic conditions. Moreover, the use of frass could be a good alternative to replace artificial fertilizers in the future. In addition, it should be taken into consideration that the mass production of frass depends strongly on the size of the insect rearing production farm.

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CRediT Authorship Contribution Statement

Arben Mehmeti: Conceived the project and supervised the work. **Arben Mehmeti, Rainer Waldhardt, Muhamet Zogaj, Hysen Bytyqi:** Conceptualization, Investigation, performed most of the experiments, analyzed the data and drafted the manuscript. **Egzon Kabashi, Drijart Mehmetaj, Labinot Kryeziu:** Performed some of the experiments. **Rainer Waldhardt, Arben Mehmeti:** contributed to the editing of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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