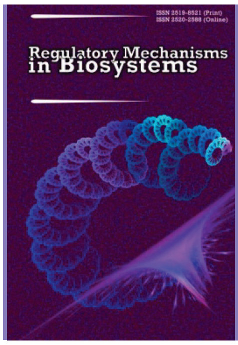

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Tillage effects on humus content in the soils of Ukraine: A meta-analysis of current scientific evidence

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Tillage is an agrotechnological factor with the strongest influence on soil properties, especially, agrophysical and agrochemical ones. Soil fertility depends on numerous soil traits, but mainly on the content of humus (soil organic matter). The current food crisis and the aggravation of negative climate impacts on environmental systems require a scientifically sound reaction of current agriculture to future challenges. Adoption of optimal tillage practices is crucial for the preservation of soil health and, consequently, for food security. The study is devoted to the meta-analysis of current scientific evidence on optimal tillage systems for Ukrainian soils in terms of humus content preservation. The meta-analysis was carried out through the standardized mean differences algorithm. The average effect size was calculated by the Cohen's distance. Publication biases were estimated using fail-safe numbers. The heterogeneity of the studies was estimated by Higgins coefficient the Chi^2 homogeneity test. Only robust domestic scientific studies were included in the meta-analysis. To search for scientific publications, the Google Scholar engine was applied. In general, 18 eligible studies out of more than 50 were enrolled and processed. It was established that there is not sufficient scientific evidence in favour of no-till systems in Ukraine. The meta-analysis provided inconclusive results because of lack of high-quality scientific research, high bias of publications and high intra-studies variability. As for the comparison between conventional ploughing and ploughless tillage systems, strong evidence was established in favour of ploughless tillage. Notwithstanding the subtle general effects size of 0.24, it was statistically significant at 95% confidence interval. Low heterogeneity and intra-studies variability strengthen the evidence in favour of ploughless tillage without soil layer inversion. More thorough scientific investigations should be performed to provide more evidence on the benefits of zero-tillage systems on Ukrainian soils.

Keywords: no-till; ploughing; ploughless tillage; soil fertility; soil organic matter; sustainability.

Introduction

Soil is irreplaceable means of agricultural production and life maintenance. Even though novel methods of crop cultivation, which require no soil (aeroponics, hydroponics), are developed and introduced, they are suitable only for limited species of plants and cannot satisfy global demand for crop products (Lakkireddy et al., 2012). Thus, soil still remains and will always be the main productive force in global agriculture (Parr et al., 1992).

Soils are one of the most important and priceless treasures of Ukraine. Ukrainian soils are among the most fertile soils in the world, and the importance of their preservation for global food security is beyond dispute (Pereira et al., 2022). This is one of the factors that transformed Ukraine, even considering the relatively lower introduction of modern innovations and machinery in the agricultural sector, into a global bread basket. For example, in 2021 Ukrainian agriculture produced 10% of global wheat grain, 15% of maize and barley, and nearly 50% of global sunflower exports were from Ukraine (Bogonos et al., 2023). That is why it is so important to preserve their qualities and minimise the harmful impacts of irrational anthropogenic activities on their fertility. The latter is especially true for irresponsible agricultural activities and tillage is particularly responsible for soil quality deterioration. Tillage is one of the most influential factors of agrotechnology, which directly effects soil quality. Irrational tillage leads to soil erosion, worsening of agrophysical, agrochemical, and meliorative properties, and results in the loss of soil organic matter and fertility. Consequently, a significant loss in the productivity of agricultural land is observed (Lal, 1993).

It is a well-established fact that Ukrainian agriculture has developed mainly though extension of cultivation for decades. It has resulted in a dangerous neglect of ecological norms for the optimal share of arable land in the general agricultural land structure. According to the World Bank data, the share of arable land in Ukraine reached 56.8% in 2021, which is a way much higher than in developed European countries, e.g., Germany (33.4%), France (32.8%), the Netherlands (29.8%), Italy (24.3%) and Spain (23.1%). Furthermore, outdated tillage machines and methods are still widely applied in Ukraine, resulting in a gradual deterioration of soil quality and loss of fertility.

Conservation of soil organic matter is one of the major tasks of current sustainable agriculture (Castellini et al., 2021). Loss of organic carbon and leaching of nutrients from the root zone of cultivated plants result in dramatic decrease in the yields and quality of crop products. Against the background of the current global food crisis, which is extremely aggravated by rapid climate change and military activities in Ukraine, the task of maintaining soil fertility has become one of the most important tasks for

Ukrainian agriculture and requires scientifically sound solutions (Solokha et al., 2022). Optimization of tillage could be one of possible measures to restrain rapid soil degradation in Ukraine and consecutive enhancement in crop production, especially considering current scientific evidence in favour of tillage as one of the measures for better soil health in the semi-arid regions of the world (Zhang et al., 2021).

To provide a scientific solution to the question of rational soil tillage in the current agro-industrial conditions of Ukraine, relevant experimental studies are required. As agricultural, soil, and climate conditions in Ukraine are quite different from those in other European countries, it is necessary to orient mainly on domestic research results. In recent decades, numerous scientific studies have been carried out to determine the direct and indirect effects of different tillage systems on soil organic matter content in different types of Ukrainian soils. Most of them involved conventional tillage practices (e.g., mouldboard ploughing) and various other options of ploughless tillage (chisel, disc) including sometimes even the newest options such as differentiated ploughless tillage with combined machines, disc-rippers, soil slitting, etc. As far as sometimes the results of methodologically similar studies are contradictory, it is difficult to draw a final conclusion on the choice of the best tillage option. Notwithstanding the fact that modern mathematics provides reliable means of studies comparison and justification of the results, for example, through a meta-analysis computation, no generalization of the reported scientific results was performed until now. Therefore, the main purpose of this study was to generalize current scientific evidence and establish the significance of effects of different tillage options on the humus content in Ukrainian soils with the main focus on soil organic matter conservation through the meta-analysis, performed using the algorithm of between the studies, in order to provide scientific substantiation of the optimal tillage systems for the preservation of soil fertility.

Materials and methods

The current study is a continuation of the series of meta-analyses, conducted at the Institute of Climate-Smart Agriculture of NAAS, devoted to the subject of tillage effects on soil properties (Lykhovyd, 2024). The meta-analysis on tillage effects on soil humus content in Ukraine was carried out using the available scientific data, published in national scientific periodicals within the time frame 1998-2024 indexed in the Google Scholar database. The total number of scientific studies related to this subject exceeds 50, but just 18 are eligible for inclusion in the meta-analysis through the standardized mean differences (SMD) algorithm. Other studies were discarded because of the low quality of evidence, lack of statistical data processing, or improper data presentation. The keywords for the search were: "soil"; "humus"; "tillage"; "organic carbon"; "organic matter"; "fertility". The publications included in the meta-analysis provided the possibility of calculating the means and standard deviations of the tillage variants studied. Generally, the selected studies were subdivided into two groups, namely: Group 1 – meta-analysis of the difference between no-till system and other tillage options (5 studies in total); Group 2 – meta-analysis of the difference between ploughless tillage options and mouldboard ploughing variants of tillage (Table 1). The studies included in the meta-analysis, embraced three main types of Ukrainian soils: chornozem (black soils), chestnut soils, and soddy-podzolic soils. The humus content in all the studies was determined by Turin in the percentage to gross soil mass in the arable layer (Popa et al., 2016). It is interesting that most studies regarding no-till practices were carried out after 2010, while ploughless tillage options have been investigated since the late 1990s with the greatest share of the studies performed within 2011–2020.

The meta-analysis was performed by the standardized mean differences (SMD) algorithm without subgroups at 95% confidence interval (CI). The average effect size was calculated by the Cohen's distance (h) method, where h = 0.20 means small effect size; 0.50 – moderate effect size; 0.80 and higher – large effect size, respectively. Fail-safe numbers were evaluated using Rosenthal's methodology to establish the influence of publication bias on the meta-analysis results. The higher the fail-safe number is, the stronger the evidence in favour of the statistical significance of differences between the studied groups is (Ellis, 2010; Beheshti et al., 2020; Borenstein et al., 2021). Forest and drapery plots for the random and fixed effect models were created to provide the visualization of the meta-analysis outcomes. The heterogeneity level of the studies was estimated by the Higgins I^2 coefficient and the Chi^2 homogeneity test (Alexander et al., 1989). The Higgins coefficient could be interpreted as follows: 25% – low heterogeneity; 50% – moderate heterogeneity; >75% – high heterogeneity (Israel & Richter, 2011). The variability between the studies in the meta-analysis of random effects model was evaluated through the calculation of tau^2 (Ariel de Lima et al., 2022).

Table 1
The list of scientific studies enrolled in meta-analysis of tillage effects on soil humus content

Groups of studies	
Group 1	Group 2
Tanchyk & Yamkovyi (2010); Pikovska (2012); Morozov & Isachenko (2018); Hlushchenko et al. (2024); Tkachenko et al. (2024)	Chernilevskyi et al. (1998); Chernilevskyi et al. (2001); Tsandur (2008); Zhuravel et al. (2009); Hololobova (2010); Remeniuk (2010); Pikovska (2012); Zubenok (2012); Balayev et al. (2013); Shevchenko (2013); Zvedeniuk et al. (2014); Evtushenko & Tonha (2017); Tkachuk & Trofymenko (2020); Tsvei et al. (2020); Gordienko & Hlushchenko et al. (2024); Tkachenko et al. (2024)

Results

The meta-analysis testified to the significant difference in soil humus content between no-till and other tillage systems (Table 2). The average size effect is moderate. However, it must be admitted that the analysis of publication bias showed that the current scientific evidence in favour of no-till could be biased, as the target significance level of 0.05 is less than the observed significance level of 0.0541 while the fail-safe number is equal to zero. The meta-analysis showed moderate general heterogeneity with the I^2 coefficient equal to 0.60, with no heterogeneity inside the no-till group (the I^2 coefficient equal to 0) and high heterogeneity inside the tillage group (the I^2 coefficient equal to 0.85). Besides, relatively high intra-studies variability was found (tau^2 = 0.53). The inconclusiveness of the meta-analysis is also proved by the P-values, which are significantly higher than standard P = 0.05 (Table 3).

Therefore, although the results of the meta-analysis favour the no-till system in terms of soil humus content preservation (Fig. 1), it is difficult to draw a final conclusion on this subject, mainly due to the biased nature of the available studies conducted in Ukraine. The drapery plot of the meta-analysis results (Fig. 2) testifies to the relatively strong evidence for no-till benefits, as well as relatively moderate level of heterogeneity of the studies. But the value of the fail-safe number equal to zero signifies the insufficient robustness of scientific evidence in this case, as well as the too wide blue zone of the drapery plot.

Table 3
The results of meta-analysis of soil humus content depending on the system of tillage

Model type	Standardized mean difference	95% confidence interval	z|t statistics	P
Common effect model	0.4422	–0.0955; 0.9799	1.61	0.1070
Random effects model	0.4479	–0.6737; 1.5694	1.11	0.3297

Regarding the meta-analysis of the difference between different ploughless tillage systems and conventional mouldboard ploughing, strong evidence was established in favour of ploughless tillage systems. Publication bias was almost impossible, as the fail-safe number reached 7 studies, which constitutes 43.75% of the total number of research reports, included in the analysis. Besides, the observed significance level was much lower than the target one: 0.0255 vs. 0.05. The general heterogeneity of the studies was low (the I^2 coefficient equal to 0.20 at the P = 0.228). The intra-studies variability was also low. The input and output data of the meta-analysis are presented in Tables 4 and 5. However, it must be admitted that the random-effects model is much less statistically reliable than the common (fixed) effect model considering the P-values. The difference between the groups of ploughing and ploughless tillage is quite subtle though (Fig. 3, 4).

Table 2
Information on the input data sets and the results of the meta-analysis of soil humus content depending on the system of tillage (all the studies enrolled in the analysis were conducted at $P < 0.05$)

Study	Group 1 (no-till)	Total number	Group 2 (tillage)	Total number	Weight (fixed model), %	Weight (random model), %	Standardized mean difference (fixed model)	Standardized mean difference (random model)
A	2.00 ± 0.71	3	1.67 ± 0.48	9	16.2	18.6	0.57 [–0.76; 1.91]	0.57 [–0.76; 1.91]
B	4.58 ± 0.05	3	4.57 ± 0.05	6	15.0	17.9	0.18 [–1.21; 1.57]	0.18 [–1.21; 1.57]
C	4.15 ± 0.08	6	3.88 ± 0.16	18	25.0	22.3	1.79 [0.71; 2.86]	1.79 [0.71; 2.86]
D	3.85 ± 0.28	6	4.00 ± 0.26	12	28.9	23.4	–0.54 [–1.54; 0.46]	–0.54 [–1.54; 0.46]
E	3.91 ± 0.23	4	3.87 ± 0.04	4	14.9	17.9	0.21 [–1.18; 1.60]	0.21 [–1.18; 1.60]
Total (95% confidence interval)	–	22	–	49	100.0	100.0	0.44 [-0.10; 0.98]	0.45 [–0.67; 1.57]

Note: heterogenity: $tau^2 = 0.53$; $Chi^2 = 9.98$; $df = 4$ ($P = 0.04$); $I^2 = 60.0\%$.

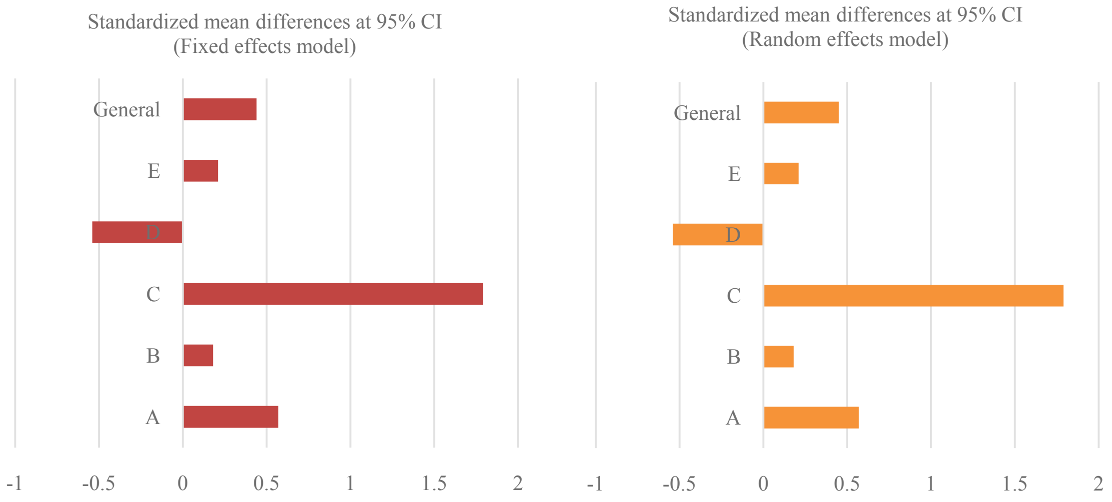

Fig. 1. The meta-analysis plots for the fixed and random effects models of the comparison between impacts of no-till and other tillage systems on soil humus content in Ukraine

The narrow blue zone of the drapery plot testifies to the statistically good evidence in favour of ploughless compared to conventional ploughing systems in terms of soil organic matter preservation. Better evidence was mainly guaranteed by a much greater number of observations, included in this meta-analysis in comparison to the meta-analysis between no-till and other tillage options (253 vs. 71), as well as a lower publication bias related to studies on various ploughless tillage options and lower variability of the studies ($tau^2 = 0.0018$ vs. 0.53).

Discussion

Meta-analysis was developed primarily as a mathematical technique to summarise and statistically substantiate the effectiveness of different treatments according to the results of several medical studies. However, it was further adopted in other branches of science as a valuable tool for the evaluation of real differences between different tested options (Israel & Richter, 2011). Nowadays, meta-analysis is an important additional instrument in summarising the results of various agricultural studies to assist researchers in finding the most prospective directions of further research work and provide scientifically sound recommendations on the general questions of agricultural technology, e.g., best tillage options. As Ding et al. (2023) stated, the main subjects of meta-analysis in agriculture in recent decades were climate change, yields of crops, soil qualities, and animal husbandry issues. The presented research was devoted to one of these four major classes, namely, the investigation of the optimal tillage system to provide soil humus content preservation.

There are several currently available meta-analyses on the above mentioned subject. For example, Githongo et al. (2021) conducted a meta-analysis of the effects of tillage minimisation on soil organic carbon content in conditions in sub-Saharan Africa. They noted that no benefits were found in tillage minimisation considering the organic matter content of the soil. One of the recent meta-analyses showed that a no-till system improves soil organic carbon storage in the upper soil layers, while mouldboard tillage is superior in providing higher organic matter content in deeper (26-35 cm) layers (Angers & Eriksen-Hamel, 2008). Therefore, it is difficult to claim that no-till can dramatically improve soil organic carbon sequestration in general because of such a fact.

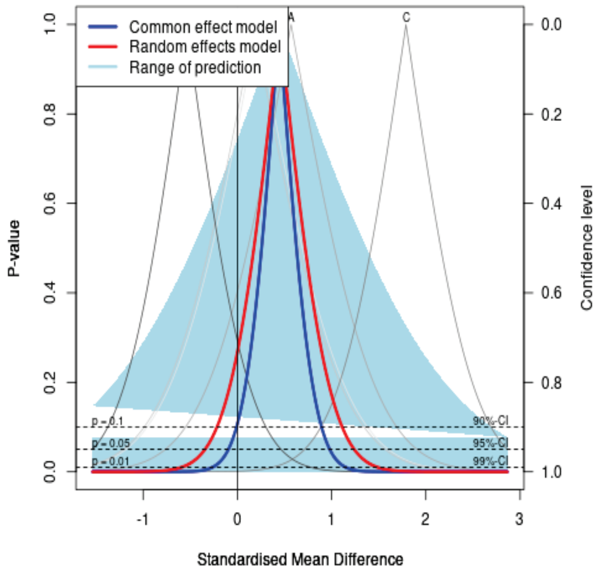

Fig. 2. The drapery plot of the meta-analysis of the comparison between no-till and other tillage systems impact on soil humus content in Ukraine

Our results as well testify that the difference in humus content in Ukrainian soils is not statistically significantly improved by no-till. Quite similar results were obtained in the meta-analysis by Ugarte et al. (2014), namely, that no-till systems provide no benefits compared to other tillage systems in terms of soil organic carbon content in the 0–30 cm soil layer. However, Haddaway et al. (2017) claimed that no-till systems resulted in higher stocks of organic carbon in the arable layer of the soils based on the systematic review of 351 studies. But it must be stressed that it was just a review without statistical data processing as in the studies with meta-analysis.

Table 4
Information on the input data sets and the results of the meta-analysis of soil humus content depending on the system of tillage (all the studies enrolled in the analysis were conducted at P < 0.05)

Study	Group 1 (ploughing)	Total number	Group 2 (ploughless)	Total number	Weight (fixed model), %	Weight (random model), %	Standardized mean difference (fixed model)	Standardized mean difference (random model)
A	4.37 ± 0.27	8	4.21 ± 0.45	8	7.5	7.5	0.41 [–0.59; 1.40]	0.41 [–0.59; 1.40]
B	3.29 ± 0.18	8	3.34 ± 0.15	16	10.2	10.2	–0.30 [–1.16; 0.55]	–0.30 [–1.16; 0.55]
C	0.95 ± 0.05	5	0.98 ± 0.04	5	4.5	4.5	–0.60 [–1.88; 0.68]	–0.60 [–1.88; 0.68]
D	2.90 ± 0.26	3	2.92 ± 0.13	6	3.9	3.9	–0.10 [–1.49; 1.29]	–0.10 [–1.49; 1.29]
E	4.54 ± 0.06	3	4.59 ± 0.04	3	2.4	2.4	–0.78 [–2.53; 0.97]	–0.78 [–2.53; 0.97]
F	3.34 ± 0.37	15	3.31 ± 0.42	30	19.3	19.1	0.07 [–0.55; 0.69]	0.07 [–0.55; 0.69]
G	4.37 ± 0.18	8	4.48 ± 0.21	32	12.1	12.0	–0.53 [–1.31; 0.26]	–0.53 [–1.31; 0.26]
H	3.74 ± 0.14	6	3.95 ± 0.14	12	6.0	6.0	–1.43 [–2.54; –0.32]	–1.43 [–2.54; –0.32]
I	3.99 ± 0.26	6	4.01 ± 0.29	6	5.8	5.8	–0.07 [–1.20; 1.07]	–0.07 [–1.20; 1.07]
J	3.93 ± 0.06	4	3.89 ± 0.09	2	2.4	2.4	0.46 [–1.28; 2.21]	0.46 [–1.28; 2.21]
K	1.12 ± 0.12	3	1.10 ± 0.18	6	3.9	3.9	0.11 [–1.28; 1.50]	0.11 [–1.28; 1.50]
L	3.56 ± 0.21	10	3.62 ± 0.25	10	9.6	9.6	–0.25 [–1.13; 0.63]	–0.25 [–1.13; 0.63]
M	4.28 ± 0.07	2	4.26 ± 0.06	6	2.9	2.9	0.28 [–1.33; 1.89]	0.28 [–1.33; 1.89]
N	1.18 ± 0.01	2	1.18 ± 0.04	4	2.6	2.6	0.00 [–1.70; 1.70]	0.00 [–1.70; 1.70]
O	1.38 ± 0.08	4	1.69 ± 0.10	8	2.1	2.1	–3.03 [–4.92; –1.14]	–3.03 [–4.92; –1.14]
P	1.20 ± 0.23	4	1.12 ± 0.31	8	5.1	5.1	0.26 [–0.95; 1.46]	0.26 [–0.95; 1.46]
Total (95% confidence interval)	–	91	–	162	100.0	100.0	–0.24 [–0.51; 0.03]	–0.24 [–0.57; 0.09]

Note: heterogeneity: $tau^2 = 0.0018$; $Chi^2 = 18.69$; df = 15 (P = 0.23); $I^2 = 20.0\%$.

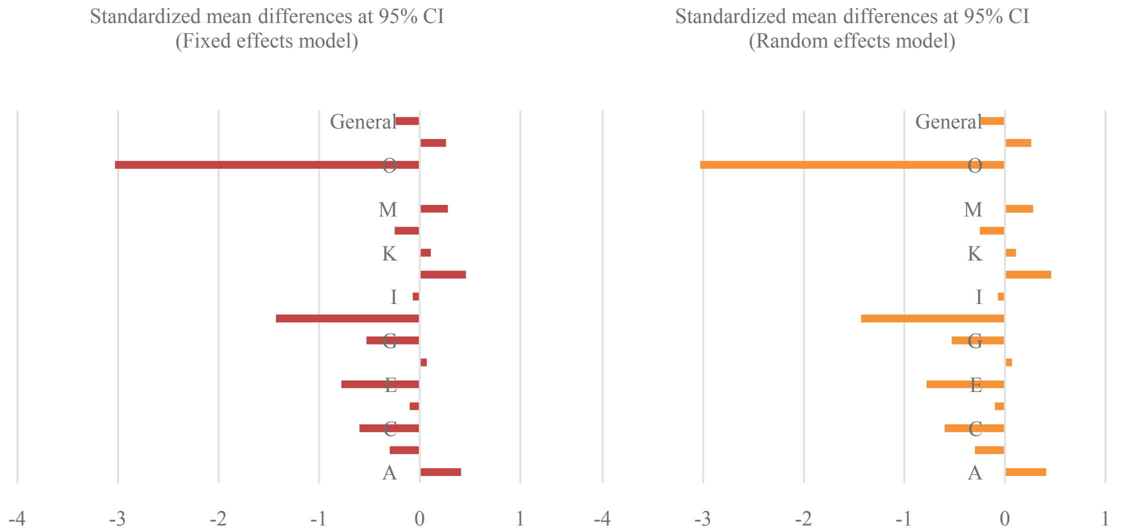

Fig. 3. The meta-analysis plots for the fixed and random effects models of the comparison between ploughless and ploughing tillage systems impacts on soil humus content in Ukraine

Table 3
The results of meta-analysis of soil humus content depending on the system of tillage

Model type	Standardized mean difference	95% confidence interval	z|t statistics	P
Common effect model	–0.2389	–0.5112; 0.0333	–1.72	0.0854
Random effects model	–0.2396	–0.5708; 0.0916	–1.54	0.1439

The meta-analysis by He et al. (2021) showed that the effect of different tillage systems on soil organic matter depends on the peculiarities of the climate of China, but in general, all conservation tillage options with different levels of tillage minimisation provided better soil organic carbon sequestration compared to conventional tillage with soil layer inversion. The global meta-analysis of 89 scientific studies testified that no-till is statistically significantly better than conventional mouldboard tillage in terms of improving soil organic carbon (Liu et al., 2021). As for other tillage options, it was proved that conservation minimal tillage is beneficial for soil fertility preservation, which agrees with our results (Crystal-Ornelas et al., 2021). Besides, additional evidence in favour of ploughless minimal tillage could be found in the meta-analysis by Topa et al. (2021), who established not only soil organic carbon improvements with tillage minimization, but also great amelioration of general soil nutritive status due to increased stocks of nitrogen, phosphorus and potassium. As the meta-analysis by Li et al. (2019) states, tillage minimization and use of ploughless machines to prepare soil provides additional benefits for soil agrophysical properties and structure, which is also important for fertility and good growth and development of the cultivated plants. As the meta-analysis based on US studies established, cutting down the implementation of full-inversion tillage machines results in improved soil organic carbon stocks, enhanced beneficial microbiota activity in soils, and are generally more beneficial to soil ecosystem health (Nunes et al., 2020).

As for Ukraine, there is no available meta-analysis regarding the effects of different tillage systems on soil humus content and organic carbon stocks. The presented study is the first conducted based on national research and provides novel information on the future strategy of the adoption of tillage practices in Ukraine to preserve soil health. Ploughless tillage should be widely implemented, while conventional deep mouldboard ploughing can take place once or twice per crop rotation just to destroy the plough-pan. Excessive ploughing must be avoided. Regarding no-till systems and direct sowing, the results are still inconclusive. More studies are required to strengthen the evidence in favour of no-till system. Notwithstanding the fact that many foreign studies and meta-analyses claim the benefits of no-till, it should be noted that these effects are incoherent under different environmental conditions.

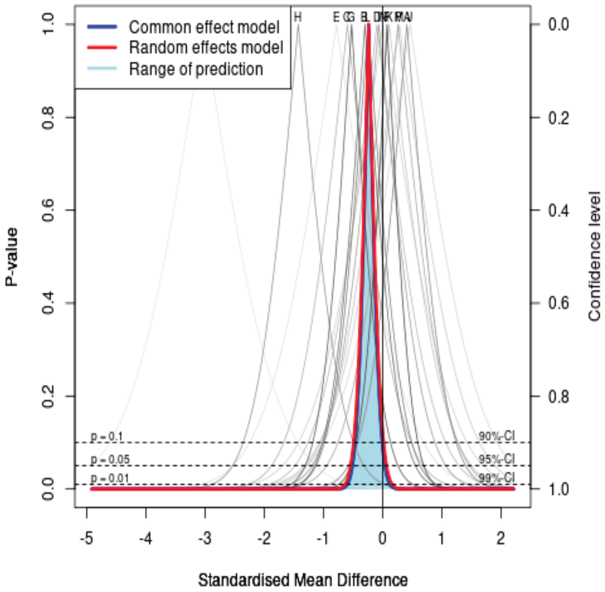

Fig. 4. The drapery plot of the meta-analysis of the comparison between ploughless and ploughing tillage systems impact on soil humus content in Ukraine

Therefore, nationwide meta-analysis for the soils of Ukraine should be conducted to draw the final conclusions on this subject, because direct adoption of foreign practices, which were studied in other climates on other types of soil, can result in fewer benefits or even can turn to be harmful. At the same time, further meta-analyses should consider the depth of different tillage options, as it was stated by Cooper et al. (2016) that shallow depth of mouldboard tillage is not inferior to minimal tillage in soil organic carbon preservation, while deep conventional tillage significantly reduces soil fertility in the arable layer.

Conclusions

The results of the meta-analysis testified that there is scientific evidence in favour of minimising soil tillage to provide better soil organic matter conservation. However, the results for different minimisation practices were different. In case of the no-till system, there is a statistically insignificant proof of its benefit over other tillage options. Also, it was found that the available studies are biased. Therefore, further unbiased investigations should be carried out in Ukraine to provide a relevant and scientifically sound solution to this question. As for the comparison between various ploughless tillage systems and conventional mouldboard ploughing, it was established that there is strong evidence in favour of ploughless tillage for soil humus content preservation. Although the difference is subtle in figures, it is statistically significant, and ploughless tillage systems should be preferred over plough-related tillage systems in Ukrainian soils. Generally, the meta-analysis supports current recommendations for soil tillage minimization to ensure preservation of fertility in the context of global climate change and related issues of ecological instability of natural ecosystems. The enrichment of the research results on the impacts of no-till on Ukrainian soil fertility will create an opportunity for a more robust meta-analysis to answer the question of whether we should support massive transfer to zero-tillage.

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