



Futureproof Sustainable Farming Guide

Practical solutions for resilient and profitable farms

FOREWORD

Ukrainian agriculture faces unprecedented challenges every day. The full-scale war, rapidly rising costs of inputs and fuel, unpredictable climate change accompanied by critical moisture shortages, and continuing soil degradation are threatening the economic stability of every farm. Farmers are forced to operate under constant pressure as traditional intensive tillage methods become too expensive and less effective. Depletion of the fertile soil layer and disruption of logistics chains require a fundamental rethink of production approaches, as the cost of every mistake is now exceptionally high.

At the same time, Ukraine's irreversible course towards European integration is opening new horizons, accompanied by new quality standards. The growing importance of sustainable agricultural practices is no longer simply a response to global environmental trends, but a basic requirement for successful operation and competitiveness in EU markets. European legislation and consumers require responsible environmental stewardship, a lower carbon footprint and more efficient use of chemicals. Adapting to these demanding requirements is a reliable way to preserve export potential. The transition to resource-efficient technologies is shaping a new image of the Ukrainian farmer as a responsible steward of the land.

In these difficult times, Ukrainian farmers need practical tools to preserve and develop their businesses. This guide is intended to serve as a reliable resource for farmers today, offering proven solutions to optimise production, reduce financial costs and manage available resources effectively amid continued uncertainty. Importantly, the guide does not merely present theory. It provides clear, step-by-step instructions on how farmers can test innovative practices themselves on a limited area of their own farm, with minimal financial risk. A detailed cost-benefit analysis supports balanced, economically sound decisions based on clear payback calculations.

The main purpose of this guide is therefore to offer practical solutions grounded entirely in objective evidence and real field data. They are intended to strengthen farm resilience, preserve and improve soil health, and ensure that agribusinesses are as well prepared as possible for future challenges. To this end, we examine minimum tillage in detail, the use of biological products to improve ecosystem health, biochar as an investment in long-term fertility, and the critical steps involved in restoring land damaged by hostilities.

TBI would like to express our sincere gratitude to all researchers, experts, practising farmers and partners who contributed to the large-scale trials and to the development of this guide. We are especially grateful to the farmers who openly shared their own experience, stories of adopting innovations and real results from their fields. We would also like to express our deep appreciation to the researchers of the L. Pogorilyy Ukrainian Scientific Research Institute of Forecasting and Testing of Machinery and Technologies for Agricultural Production and Mykolaiv National Agrarian University for their scientific expertise, dedication and invaluable contribution to the field trials and development of this guide, as well as to BTU for its advisory support and commitment to advancing sustainable practices.

We extend our special gratitude to Minderoo for its generous support of this initiative and its continued commitment to strengthening Ukrainian agriculture, supporting farmers and fostering innovation during these challenging times. Thanks to this collective commitment, Ukrainian farmers now have access to a strong practical knowledge base adapted to local realities, supporting confident development, food security and the restoration of the country's agricultural potential.

01

GETTING STARTED: WHAT IS WORTH TESTING ON YOUR FARM

1.1. How to use this guide

This guide has been developed as a practical toolkit for Ukrainian farmers looking for effective ways to adapt to today's challenges, from climate change and economic instability to the consequences of war. Its main purpose is to provide objective solutions, based on scientific research and real field data, for introducing resource-efficient and restorative technologies. The document offers practical action plans for safely testing new approaches with minimal financial risk. The data and the photos you see in this guide are from the fields of our trials.

Use this guide to move from a problem on your farm to a practical decision:

01

identify practices that may be relevant to their farm

02

understand the evidence supporting their effectiveness

03

assess costs, benefits and risks

04

test promising practices on a limited area

05

decide whether to scale up the practice, repeat the trial or discontinue it

1.2. Who this guide is for

01

Farmers and landowners to optimise costs, protect investments and support long-term profitability and soil health.

02

Farm managers to calculate economic viability, assess risks and make informed decisions on introducing new practices.

03

Agonomists to access an evidence base and clear step-by-step instructions for safely testing resource-efficient technologies directly in the field.

1.3. Practices put to the test

Four practices are examined through field evidence, economics and a practical route to testing:

01 Minimum tillage	02 Biological products
03 Biochar	04 Restoration of soils damaged by war

1.4. Behind the evidence

- **Trial locations:** the fields of the Ukrainian Research Institute for Forecasting and Testing of Machinery and Technologies for Agricultural Production (UkrNDIPVT) named after Leonid Pohorilyi (for the minimum tillage, biological products and biochar trials, Modules 2-4) and Slavutych Farm in Yasna Poliana, Mykolaiv Oblast (soil restoration research, Module 5).
- **Crops:** the main trials were conducted on spring barley (Lexi variety) and spring wheat (Likamero variety). Mustard was grown as a green manure crop as part of the research on contaminated land (Module 5).
- **Years:** the field trials for this guide were conducted in 2026. They also draw on the substantial scientific evidence base of the L. Pohorilyi UkrNDIPVT, where minimum tillage has been studied since 2008 and biological products since 2010. The project's own experimental data were also supplemented with broader international and Ukrainian academic research.
- **Farm and climatic conditions:** trials at the L. Pohorilyi UkrNDIPVT fields in southern Kyiv Oblast were established on level ground with deep, low-humus, medium-loam chernozem. Weather conditions were extremely variable: a moisture deficit in spring and drought from late June through August alternated sharply with heavy rainfall in May and early June. These pronounced moisture fluctuations placed the plants under stress, providing a useful test of moisture-conservation technologies. Research on contaminated land (Module 5) was carried out under dry steppe conditions in Mykolaiv Oblast.
- **Limitations:** the results presented reflect crop responses to specific soil and climatic factors and particular machinery. It is important to remember that results obtained in one location may not apply equally under different conditions. Your own soil type, climate, crop, machinery and farm-management approach are decisive. These data should therefore be used as a reference point, but before making a final decision you should always conduct a small-scale trial on your own farm.

1.5. Start with the challenge

My main problem	Practice to consider	Go to
High fuel or machinery costs	Reduced tillage	Module 2

My main problem	Practice to consider	Go to
Moisture shortage or drought	Reduced tillage Biochar	Module 2 Module 4
Improving crop performance or resource-use efficiency	Biological products	Module 3
Improving soil condition over the long term	Biochar	Module 4
Restoring land damaged by war	Restoration of soils damaged by war	Module 5
Testing a promising practice independently	Low-risk on-farm trial	Module 6

1.6. From evidence to decision

For each practice, ask yourself the following questions:

1. What problem could this practice help solve?
2. Is it suitable for my farm?
3. What does the available evidence show?
4. What are the main risks and requirements?
5. Is the practice economically viable for my farm in terms of its costs and benefits?
6. How can I test it on a limited area?
7. Should I scale up the practice, run another trial or discontinue it?

1.7. Reading the results

Remember:

- Results obtained in one location may not apply equally under different conditions.
- Soil, climate, crop, machinery and farm-management practices all matter.
- Higher yields do not necessarily mean higher profits.
- A small-scale trial on your own farm helps determine whether a practice works under your specific conditions.

2.1. Reduced tillage, explained

What is reduced tillage?

Reduced tillage is a farming approach that avoids conventional deep ploughing and soil inversion. Instead, the soil could be left undisturbed or loosened only near the surface, to a depth of 10-18 cm, using disc or tine implements.

A key rule of this technology is to retain crop residues, including straw and stubble, on the soil surface. These organic residues create a natural protective layer, or mulch. It performs several important functions: it protects the fertile soil layer from wind erosion and wash-off during rainfall, while also acting as an insulating shield from the sun. As a result, soil moisture is retained much more effectively, which is critical for plants during summer heat and drought. Note that after this type of tillage the soil surface will look considerably more 'untidy' than after conventional preparation, with weeds and crop residues remaining visible. Some farmers find this change in field appearance difficult to get used to. It may require a shift in the familiar idea of what a 'clean' soil surface should look like.

Reducing mechanical disturbance also helps preserve the soil's natural structure. This creates favourable conditions for beneficial microflora and earthworms. The soil retains nutrients more effectively and restores its fertility more quickly. As a result, the farmer not only protects the field from depletion but also saves substantial amounts of fuel and other resources during field operations.

Which approaches were assessed?

- **Minimum tillage (Mini-till).** This is a ploughless system limited to shallow loosening at a depth of 10-18 cm without inverting the soil layer. It partially mixes crop residues into the upper soil layer, significantly reduces the number of passes by heavy machinery and helps preserve the natural water and air permeability of the topsoil.
- **Strip tillage (Strip-till).** This technology involves deep vertical loosening, at 15-30 cm, only in narrow strips where seed is subsequently sown and fertiliser applied locally. At the same time, 70-80% of the field area between rows remains completely undisturbed and covered with organic mulch. The approach combines the advantages of conventional tillage, by creating a loose and warmed seedbed, with those of no-till, by maximising moisture retention between the rows.
- **Conventional tillage.** The traditional benchmark is conventional mouldboard ploughing, which completely inverts the soil layer to a depth of 25-35 cm. This method effectively

incorporates crop residues and suppresses weeds, but it has significant disadvantages. It completely disrupts the soil's natural architecture, accelerates moisture loss through intensive evaporation from the exposed surface, and requires the highest fuel and time inputs.

What problems can this practice help solve?

01

Moisture shortages: crop residues on the field surface reduce water evaporation and retain moisture effectively for plant use.

02

Wind and water erosion: natural plant cover reliably protects the fertile soil layer from being blown away by wind or washed away by heavy rainfall.

03

High production costs: reducing the number of machinery passes can substantially cut expenditure on diesel, repairs and labour.

04

Inefficient fertiliser use: strip tillage allows fertiliser to be applied locally in the root zone, reducing total use by 30-50% without loss of effectiveness.

05

Loss of soil fertility: avoiding soil inversion helps restore populations of beneficial microorganisms and earthworms and supports the gradual accumulation of humus.

06

Temperature stress for seedlings: mulch acts as a natural thermal insulator, smoothing sharp temperature fluctuations and protecting plants from overheating or excessive cooling.

07

Missing the optimal sowing window: locally tilled strips warm and dry much faster than a fully ploughed field, allowing sowing to begin on time.

Main potential benefits

01

Strong root development: loosening the soil only in the plant growth zone allows roots to penetrate deeply, down to 90 cm, and access water even during intense heat.

02

Stable yields in drought: thanks to moisture retained beneath crop residues and precise fertiliser placement, plants can produce better yields than under ploughing, particularly in adverse dry years.

03

Lower machinery and labour requirements: one modern implement can perform the work of several conventional machines, speeding up operations and reducing the farm's dependence on scarce tractor operators.

04

Financial resilience: because fuel and fertiliser costs are significantly lower, it is easier for the farmer to recover investment and remain profitable even at modest yields.

05

Natural soil enrichment: crop residues left on the surface gradually decompose and turn into natural fertiliser (humus), making the field more fertile and biologically active over time.

2.2. Is minimum tillage suitable for my farm?

Table 1. Quick farm assessment



Quick Farm Assessment

Is minimum tillage suitable for my farm?

Assess your conditions and tick the points that best match your situation.

Lower costs – more opportunities!



This practice may be suitable for you if:


☐

You are looking for a way to significantly reduce diesel fuel costs and shorten the time needed to carry out field operations.


☐

Your fields often suffer from strong winds or heavy rainfall that blow or wash away the most valuable topsoil layer.


☐

Your fields have relatively level terrain, allowing machinery to maintain a stable tillage depth.



Consider the decision carefully if:


☐

Your fields are dominated by heavy clay soils that are often waterlogged and slow to dry out in spring.


☐

Your fields are heavily infested with perennial weeds (for example, creeping thistle or couch grass), which will require more intensive chemical control.


☐

Your combines do not have high-quality straw choppers, which results in uneven piles of straw remaining in the field.



This practice may be unsuitable if:


☐

There is a dense “plough pan” in the soil (a hardened layer below the ploughing depth), which you do not plan to break up in advance through deep loosening.


☐

You use old or lightweight seed drills that cannot cut through the straw layer and ensure seeds are placed at the correct depth.


☐

Your soils have high acidity and require regular lime application, which needs to be thoroughly incorporated into the soil.



Remember!

Minimum tillage is not just a technology; it is a solution that works best under the right conditions.



Most importantly — consider:


☒

Soil type and condition


☒

Weather conditions in your region


☒

Your farm's technical capacity

The right choice means a stable harvest!

2.3. Evidence from the field

Our trial

- **Location:** Doslidnytske settlement, Bila Tserkva Raion, Kyiv Oblast (trial fields of the L. Pohorilyi UkrNDIPVT).
- **Year:** 2026
- **Crop(s):** spring barley (Lexi variety) and spring wheat (Likamero variety).
- **Soil conditions:** deep, low-humus, medium-loam chernozem. Level terrain with an even microrelief.
- **Climate and moisture conditions:** weather in southern Kyiv Oblast in 2026 was highly variable. Only 292.7 mm of precipitation fell from January to August, equivalent to 66.1% of the long-term norm. A dry March and drought during the sowing period in late April (hydrothermal coefficient, HTC, 0.71; values below 1 indicate a moisture deficit), followed by drought from late June through August (HTC 0.00–0.52), alternated sharply with good moisture conditions in May and early June (HTC 1.14–1.61). Overall, the season was very dry, with an average HTC of 0.596, placing crops under substantial moisture stress and further demonstrating the importance of moisture-conserving tillage technologies.
- **Farm conditions:** a 15.36 ha experimental site divided into eight demonstration plots. Previous crops: buckwheat and winter wheat.
- **Trial design:** comparison of three tillage systems: Mini-till (two machinery options, a Ukrainian equipment set and a foreign equipment set), Strip-till and conventional tillage.

Machinery used:

- *Conventional:* PLN-4-40 plough + John Deere 6195M tractor; Pallada 6000 disc harrow + John Deere 6195M tractor; Axis 30.1 mineral fertiliser spreader + MTZ 1025 tractor; ZKKShP-6 ring-spur rollers + MTZ 80 tractor; SZM-4 Nika seed drill + MTZ 1025 tractor.
- *Mini-till (Ukrainian machinery):* Axis 30.1 mineral fertiliser spreader + MTZ 1025 tractor; APOG-6 pre-sowing tillage unit + John Deere 6155M tractor; SZM-4 Nika seed drill + MTZ 1025 tractor.
- *Mini-till (foreign machinery):* Lemken Compact-Solitair 9/400 HD seed drill combination + John Deere 6195M tractor.
- *Strip-till:* Mzuri Pro-Til 6T seed drill combination + CLAAS Axion 950 tractor.

Indicators measured:

- *Operational indicators:* fuel consumption, productivity and travel speed.
- *Soil-condition indicators:* bulk density, crumbling, hardness, moisture and depth of the loosened layer.
- *Field-condition indicators:* weed infestation and surface ridging.
- *Sowing-quality indicators:* deviation of the actual seed rate from the target, number of seeds left uncovered, sowing uniformity and seed placement depth.
- *Environmental indicators:* CO₂ emissions (calculated data).
- *Yield indicators:* biological yield and harvested yield.

What did the trials show?

Table 2. Comparative analysis of agronomic and economic indicators by tillage system

Indicator	Practice	Spring wheat (value / difference vs baseline)	Spring barley (value / difference vs baseline)
Yield, t/ha	Conventional ploughing (BASELINE)	4,80 / –	4,90 / –
	Mini-till (Ukrainian)	4,74 / –0,06	4,83 / –0,07
	Mini-till (foreign)	4,43 / –0,37	4,88 / –0,02
	Strip-till	4,51 / –0,29	4,85 / –0,05
Fuel use, l/ha	Conventional ploughing (BASELINE)	89,0 / –	89,0 / –
	Mini-till (Ukrainian)	41,2 / -47,8	41,2 / -47,8
	Mini-till (foreign)	42,7 / -46,3	42,7 / -46,3
	Strip-till	48,2 / -40,8	48,2 / -40,8
Number of machinery passes	Conventional ploughing (BASELINE)	8 / –	8 / –
	Mini-till (Ukrainian)	5 / –3	5 / –3
	Mini-till (foreign)	3 / –5	3 / –5
	Strip-till	3 / –5	3 / –5
Plant-available moisture (0-20 cm layer), mm	Conventional ploughing (BASELINE)	sowing: 29.1 / – harvest: 12.6 / –	sowing: 24.8 / – harvest: 12.3 / –
	Mini-till (Ukrainian)	sowing: 24.8 / -4.3 harvest: 11.9 / -0.7	sowing: 25.3 / +0.5 harvest: 13.4 / +1.1
	Mini-till (foreign)	sowing: 25.2 / -3.9 harvest: 13.2 / +0.6	sowing: 27.5 / +2.7 harvest: 13.4 / +1.1
	Strip-till	sowing: 24.9 / -4.2 harvest: 13.3 / +0.7	sowing: 24.1 / -0.7 harvest: 13.1 / +0.8
Soil bulk density, g/cm³	Conventional ploughing (BASELINE)	sowing: 1.04 / – harvest: 1.15 / –	sowing: 1.03 / – harvest: 1.11 / –
	Mini-till (Ukrainian)	sowing: 1.16 / +0.12 harvest: 1.14 / -0.01	sowing: 1.04 / +0.01 harvest: 1.23 / +0.12
	Mini-till (foreign)	sowing: 1.16 / +0.12 harvest: 1.20 / +0.05	sowing: 1.12 / +0.09 harvest: 1.18 / +0.07

Indicator	Practice	Spring wheat (value / difference vs baseline)	Spring barley (value / difference vs baseline)
	Strip-till	sowing: 1.18 / +0.14 harvest: 1.21 / +0.06	sowing: 1.02 / -0.01 harvest: 1.16 / +0.05
Weed density, plants/m²	Conventional ploughing (BASELINE)	3,0 / -	2,5 / -
	Mini-till (Ukrainian)	5,8 / +2,8	4,7 / +2,2
	Mini-till (foreign)	6,0 / +3,0	5,3 / +2,8
	Strip-till	4,5 / +1,5	4,2 / +1,7
Labour input, person-hours/ha	Conventional ploughing (BASELINE)	3,1 / -	3,1 / -
	Mini-till (Ukrainian)	1,5 / -1,6	1,5 / -1,6
	Mini-till (foreign)	1,1 / -2,0	1,1 / -2,0
	Strip-till	1,0 / -2,1	1,0 / -2,1
Production cost, UAH/ha	Conventional ploughing (BASELINE)	29 675,1 / -	27 179,9 / -
	Mini-till (Ukrainian)	25 850,9 / -3 824,2	23 395,4 / -3 784,5
	Mini-till (foreign)	26 231,8 / -3 443,3	23 736,5 / -3 443,4
	Strip-till	26 442,2 / -3 232,9	23 946,9 / -3 233,0
Fuel-related CO₂ emissions, kg/ha	Conventional ploughing (BASELINE)	235,0 / -	235,0 / -
	Mini-till (Ukrainian)	108,8 / -126,2	108,8 / -126,2
	Mini-till (foreign)	112,7 / -122,3	112,7 / -122,3
	Strip-till	127,2 / -107,8	127,2 / -107,8

Note: Data were calculated from the trial results for spring wheat and spring barley grown on control plots without biological products or additional soil amendments.

Consistency of the results with global experience

Our data are fully consistent with global trends. International agronomic experience shows that the main advantage of minimum tillage is not a rapid increase in yield, but a substantial reduction in expenditure on fuel, machinery operation and labour. Overall farm profitability can increase through significant resource savings, allowing a higher net margin even with the same or slightly lower gross output.

Yield dynamics: features of the transition period

A small reduction in yield, of 0.4-7.7% in our trial, during the first year is entirely normal when changing technology. Moving away from intensive mechanical disturbance begins a longer-term process of soil recovery. During the first 2-3 years, the soil passes through a so-called 'transition period': its natural porous structure recovers, organic mulch accumulates and the microbiome stabilises. Once this process is complete, yields level out and, in dry and stressful years, can exceed those under conventional ploughing because moisture is retained more effectively.

Labour savings and addressing staff shortages

The transition from conventional ploughing to minimum tillage, particularly Strip-till or Mini-till with foreign machinery combinations, can reduce machinery-operator labour time by 2.5-3 times. Around two hours of labour are saved per hectare, which is critically important in the context of today's staff shortages.

Field appearance and the myth of weed infestation

Farmers often worry that a field under minimum tillage (Mini-till) will look 'untidy' or excessively weedy. Real photographs from our trial show otherwise.



Picture 1. General view from the combine cab of a spring wheat plot sown using conventional technology

As the photographs show, the spring wheat plot grown under Mini-till looks almost as tidy as the conventionally ploughed plot. There is no striking visual difference between them. If examined very closely immediately before harvest, the Mini-till plots show a slightly higher number of annual weeds, mainly isolated lamb's quarters and amaranth plants. However, this level is entirely safe and does not exceed the acceptable threshold.



Picture 2. General view of a spring wheat plot sown using Mini-till technology

Key conclusion: correctly applied Mini-till maintains an appropriate appearance and phytosanitary condition of the field. The presence of isolated weeds is normal and usually does not affect final yield. In our trial this meant no additional herbicide expenditure was required, although each farm should take account of its own field history. Where initial weed pressure is high, the crop-protection programme may need to be adjusted.

Summary of international experience

The scientific literature generally indicates that minimum, reduced or zero tillage can improve farm profitability compared with conventional ploughing, primarily by reducing expenditure on fuel, machinery hours, labour and equipment operation. The exact effect depends on the farming system, farm scale, soil type and climate, while in some cases additional herbicide expenditure can partly offset the savings.

For example, an economic analysis in Denmark¹ found that reduced tillage increased farm profits by US\$90-150/ha, depending mainly on farm size, while also reducing fuel consumption. Importantly, reduced tillage remained more profitable than conventional tillage even under constraints on increased pesticide use. A field trial in north-eastern Germany similarly² found reduced tillage to be the most profitable system, generating net returns of US\$160/ha.

North American evidence shows similar results. Long-term trials in western Kansas³ compared conventional, reduced and no-till systems in a wheat-sorghum-fallow rotation. Average returns under no-till were around US\$146/ha higher than under conventional tillage and US\$76/ha higher than under reduced tillage. In this case, the advantage was due not only to lower mechanical tillage requirements, but also to substantially higher sorghum yields under no-till. More recent US soybean studies found average savings in tillage costs of US\$179/ha, with annual savings of US\$97-183/ha after switching from conventional to no-till.

Taken together, these European and North American studies suggest an indicative annual financial benefit of around US\$100-180/ha from moving from conventional soil preparation to

¹ Jacobsen, B. H. and Ørum, J. E. (2009) 'Farm economic and environmental effects of reduced tillage', *Food Economics – Acta Agriculturae Scandinavica, Section C*, 6(2), 134–142. <https://doi.org/10.1080/16507540903549474>

² Verch, G., Kächele, H., Höltl, K., Richter, C. and Fuchs, C. (2009) 'Comparing the profitability of tillage methods in Northeast Germany – A field trial from 2002 to 2005', *Soil & Tillage Research*, 104(1), 16–21. <https://doi.org/10.1016/j.still.2008.12.012>

³ Vandeveer, M., Holman, J. D., Schlegel, A., O'Brien, D., Obour, A. K., Haag, L. and Assefa, Y. (2023) 'Economics of alternative tillage systems in dryland crop rotations in US Great Plains', *Soil & Tillage Research*, 232, 105751. <https://doi.org/10.1016/j.still.2023.105751>

minimum/reduced/no-till. This figure should, however, be treated as an indicative estimate derived from the literature rather than guaranteed savings for any individual farm, as outcomes can be significantly affected by yield, weed-control costs, machinery availability and farm scale.

What does the broader academic evidence show?

- **Comprehensive economic and agronomic efficiency:** domestic studies confirm that the adoption of strip-till is a highly effective, resource-efficient solution that allows farmers to achieve two goals simultaneously – significantly increase the yield of row crops (corn and soybeans by 17–30%) while more than halving diesel fuel consumption, labor hours, and direct operating costs compared to traditional plowing.⁴
- **Reduced compaction:** long-term use of minimum and non-inversion tillage at an appropriately selected depth can help improve the physical condition of the soil, reduce mechanical resistance and create more favourable conditions for roots to penetrate deeper layers.⁵
- **Effective moisture retention:** shallow minimum tillage combined with retention of crop residues on the soil surface helps preserve moisture in the upper soil layer and seed zone (0–10 cm), potentially creating more favourable conditions for germination and early plant development.⁶
- **Preservation of nitrogen reserves:** minimising mechanical disturbance is associated with a higher total nitrogen content in the upper soil horizon (0–15 cm) compared with conventional tillage methods.⁷
- **Accumulation of organic carbon:** systematic minimum tillage produces a measurable increase in soil organic matter, and potentially humus over time, as well as carbon in the upper 0–15 cm soil layer.⁸
- **Restoration of the soil ecosystem:** avoiding inversion of the soil layer supports growth in beneficial soil-fauna populations, which are critically important for natural soil-formation processes.⁹

⁴ Shustik, L., Novokhatskyi, M., Stepchenko, S., Sydorenko, S. and Maidanovych, N. (2024) 'Improving technical and technological solutions for strip tillage', *Technical and Technological Aspects of Development and Testing of New Machinery and Technologies for Agriculture of Ukraine*, 34(48), 75–92. [https://doi.org/10.31473/2305-5987-2024-1-34\(48\)-7](https://doi.org/10.31473/2305-5987-2024-1-34(48)-7)

⁵ Tsentylo, L. V. and Tsiuk, O. A. (2019) 'Dynamics of changes in soil hardness depending on primary tillage', *Bulletin of Poltava State Agrarian Academy*, 1, 147–153. <https://doi.org/10.31210/visnyk2019.01.19>

⁶ Hanhur, V., Len, O. and Hanhur, M. (2021) 'Effect of reduced tillage on moisture availability and productivity of spring barley in the Left-Bank Forest-Steppe zone of Ukraine', *Scientific Progress & Innovations*, 1, 128–134. <https://doi.org/10.31210/visnyk2021.01.15>

⁷ Hanhur, V. V., Len, O. I. and Hanhur, M. V. (2022) 'Effect of different tillage systems on the soil nutrient regime under winter wheat and spring barley in the Left-Bank Forest-Steppe zone of Ukraine', *Bulletin of Poltava State Agrarian Academy*, 1, 38–44. <https://doi.org/10.31210/visnyk2022.01.04>

⁸ Balaiev, A. D., Tonkha, O. L., Pikovska, O. V., Havryliuk, M. M. and Shemetun, K. V. (2020) 'Humus content and physicochemical properties of Forest-Steppe chernozems under reduced tillage and biologisation of the fertilisation system', *Bulletin of Agricultural Science*, 11, 24–31. <https://doi.org/10.31073/agrovisnyk202011-03>

⁹ Voitovyk, M., Prymak, I., Kachan, L., Panchenko, O. and Obrazhii, S. (2026) 'Changes in the population of earthworms in typical chernozem and the productivity of specialised field crop rotations depending on tillage and fertilisation systems', *Technical and Technological Aspects of Development and Testing of New Machinery and Technologies for Agriculture of Ukraine*, 1(38/52), 99–113. [https://dx.doi.org/10.31473/2305-5987-2025-2-38\(52\)-9](https://dx.doi.org/10.31473/2305-5987-2025-2-38(52)-9)

FARMER STORY

Viktor Sheremeta: Strip-Till is an investment in moisture, soil and farm economics



Viktor Sheremeta is the head of Hercules Farm in Kyiv Oblast, which cultivates around 2,000 ha of land. The farm uses Strip-Till technology, allowing it to conserve moisture, reduce fuel use and lower seeding rates at the same time.

'For us, Strip-Till is first and foremost about conserving moisture. This is particularly important for winter rapeseed, where so much depends on the amount of rainfall during sowing. We create conditions that allow the plant to establish even when rainfall is insufficient,' says Viktor Sheremeta.

By conserving moisture, the farm is less dependent on rainfall during the sowing period. At the same time, reducing the number of machinery passes delivers substantial fuel savings: while deep loosening can require up to 20 l/ha, Strip-Till uses only 7-8 l/ha.

Another economic effect is lower seed use. 'One advantage of this system is that, with a 70 cm row spacing, we save seed compared with full-width sowing.' Whereas the farm previously sowed winter rapeseed at 600,000 seeds per hectare, the rate is now 250,000-280,000. 'So we now use around half as much seed,' the farmer explains.

At the same time, Strip-Till requires careful adherence to the technology. After cereals, up to 10 t/ha of straw may remain on the field. If it is poorly chopped and distributed, crop residues can interfere with subsequent machinery operations. At Hercules, this problem was addressed through vertical discing: specialised discs cut the straw without mixing it into the soil.



Pictures 3 and 4. Strip-Till with simultaneous fertiliser application at Hercules Farm

This approach has an additional benefit: the straw remains on the surface, the soil heats up less and moisture evaporates more slowly.

However, surface residues and volunteer plants can also create favourable conditions for pests. The farm therefore uses preventive protection: when volunteers emerge before sowing, an insecticide treatment is applied. This approach helped avoid significant damage to winter rapeseed seedlings from cutworm that had been observed on other farms.



Picture 5. Field after strip tillage: clearly visible strips of loosened soil with retained stubble



Picture 6. Rapeseed field sown using Strip-till technology

'Any technology works only when you look not at one individual benefit, but at the whole system. If residues remain, pests have to be controlled. If we work with Strip-Till, the field has to be prepared properly. There is no single universal operation here. The result depends on a combination of correctly selected decisions,' Viktor Sheremeta emphasises.

The experience of Hercules shows that Strip-Till is not simply a way to reduce the number of tillage operations. It is a system in which moisture conservation, fuel savings and seed savings work together, but the outcome depends on how accurately the farm takes account of field-specific conditions and manages risks.

'For me, investing in technology is not just about buying machinery or changing the tillage method. It is an investment in making sure the land works for the farm over the long term and continues to deliver results. If we can conserve moisture, use less fuel and seed, and at the same time maintain soil fertility, that is an economic model that makes sense in the long term,' Viktor Sheremeta concludes.

2.4. The economics of reduced tillage

Additional costs: All direct variable costs either remain at the level of conventional technology, such as seed and agrochemicals, or decrease significantly. In some cases, however, additional expenditure on agrochemicals may arise. Another possible exception is the need for one-off capital investment to upgrade the machinery fleet, the scale of which will depend on the farm's existing technical base.

Potential savings:

- **Fuel savings (45.8-53.7%):** under conventional tillage, fuel use was 89.0 l/ha. Switching to Mini-till with Ukrainian machinery reduced it to 41.2 l/ha, a saving of 47.8 l/ha, while Strip-till reduced it to 48.2 l/ha, a saving of 40.8 l/ha. In monetary terms, this saves UAH 2,382-3,012/ha. Fuel used for autumn ploughing in 2025, 30 l/ha, is costed at UAH 47/litre; the remaining operations are costed at UAH 90/litre.
- **Savings on machinery operation and labour:** the number of field operations falls from 8 under ploughing to 3-5 under Mini-till or Strip-till. Machinery-operator labour input falls two- to threefold, from 3.1 to 1.0-1.5 person-hours/ha.

- **Total savings:** overall, minimum tillage reduced total production costs by UAH 3,233-3,824/ha compared with the baseline technology.

Impact on income: this indicator captures the opportunity cost of a small reduction in yield. In our trial, conventional ploughing on the control plots produced a spring wheat yield of 4.80 t/ha, compared with 4.74 t/ha under Mini-till. The difference is only 0.06 t/ha, or 60 kg per hectare. At a market sale price of UAH 7,000 per tonne, this 60 kg represents UAH 420 in foregone revenue. The reduction is, however, very small and does not materially affect the overall financial resilience of the model.

Indicative net benefit: despite UAH 420 in foregone revenue from the 60 kg/ha wheat yield shortfall, the production-cost saving under Ukrainian Mini-till was UAH 3,824.2/ha. The resulting net economic effect (additional profit) was +UAH 3,404.2/ha.

Break-even point: this is the most important indicator for assessing risk. It is calculated by dividing the amount saved, UAH 3,824.2, by the price of one tonne of grain, UAH 7,000. The result, 0.55 t/ha or 550 kg/ha, represents a 'safety cushion'. In other words, Mini-till is sufficiently cheaper to operate that even if its use led to a yield reduction of around half a tonne compared with ploughing, due to compaction, weather or other factors, the farmer would still avoid a loss. The conventional system justifies its higher cost only if it can consistently deliver at least 550 kg/ha more yield than Mini-till every year.

Table 3. Detailed cost-benefit analysis (CBA) by tillage system (per 1 ha)

Indicator	Practice	Spring wheat (value / difference vs baseline)	Spring barley (value / difference vs baseline)
Yield, t/ha	Conventional ploughing (BASELINE)	4,80 / -	4,90 / -
	Mini-till (Ukrainian)	4,74 / -0,06	4,83 / -0,07
	Mini-till (foreign)	4,43 / -0,37	4,88 / -0,02
	Strip-till	4,51 / -0,29	4,85 / -0,05
Fuel cost, UAH/ha	Conventional ploughing (BASELINE)	6 720,0 / -	6 720,0 / -
	Mini-till (Ukrainian)	3 708,0 / -3 012,0	3 708,0 / -3 012,0
	Mini-till (foreign)	3 843,0 / -2 877,0	3 843,0 / -2 877,0
	Strip-till	4 338,0 / -2 382,0	4 338,0 / -2 382,0
Machinery operation, UAH/ha	Conventional ploughing (BASELINE)	2 783,8 / -	2 801,1 / -
	Mini-till (Ukrainian)	2 097,5 / -686,3	2 151,0 / -650,1
	Mini-till (foreign)	2 367,1 / -416,7	2 384,3 / -416,8
	Strip-till	2 090,9 / -692,9	2 108,1 / -693,0

Indicator	Practice	Spring wheat (value / difference vs baseline)	Spring barley (value / difference vs baseline)
Labour cost, UAH/ha	Conventional ploughing (BASELINE)	239,1 / -	239,7 / -
	Mini-till (Ukrainian)	113,2 / -125,9	117,3 / -122,4
	Mini-till (foreign)	89,5 / -149,6	90,1 / -149,6
	Strip-till	81,1 / -158,0	81,7 / -158,0
Total production costs, UAH/ha	Conventional ploughing (BASELINE)	29 675,1 / -	27 179,9 / -
	Mini-till (Ukrainian)	25 850,9 / -3 824,2	23 395,4 / -3 784,5
	Mini-till (foreign)	26 231,8 / -3 443,3	23 736,5 / -3 443,4
	Strip-till	26 442,2 / -3 232,9	23 946,9 / -3 233,0
Revenue, UAH/ha <i>(wheat: UAH 7,000/t; barley: UAH 6,000/t)</i>	Conventional ploughing (BASELINE)	33 600,0 / -	29 400,0 / -
	Mini-till (Ukrainian)	33 180,0 / -420,0	28 980,0 / -420,0
	Mini-till (foreign)	31 010,0 / -2 590,0	29 280,0 / -120,0
	Strip-till	31 570,0 / -2 030,0	29 100,0 / -300,0
Net benefit (profit), UAH/ha	Conventional ploughing (BASELINE)	3 924,9 / -	2 220,1 / -
	Mini-till (Ukrainian)	7 329,1 / +3 404,2	5 584,6 / +3 364,5
	Mini-till (foreign)	4 778,2 / +853,3	5 543,5 / +3 323,4
	Strip-till	5 127,8 / +1 202,9	5 153,1 / +2 933,0

Note: Data were calculated from the trial results for spring wheat and spring barley grown on control plots without biological products or additional soil amendments.

What has the greatest impact on the result?

The main driver of the economic benefit is the substantial reduction in diesel consumption, accounting for around 74-84% of the overall cost reduction. Avoiding deep mouldboard ploughing and reducing the number of machinery passes more than offsets any potential losses from a small reduction in absolute yield.

Sensitivity analysis

- **If fuel prices increase by 20%:** the cost of conventional ploughing rises particularly rapidly. Mini-till savings increase by a further approximately UAH 600/ha, raising the net benefit to around UAH 4,000/ha.

- **If grain prices fall to UAH 5,000/t:** the revenue loss from a 0.06 t/ha yield shortfall is only UAH 300. In this case, the net benefit from Mini-till rises to around UAH 3,500/ha. The lower the grain price, the less economical the conventional technology becomes.
- **If Mini-till yields fall:** if yield under minimum tillage falls to 4.25 t/ha, 0.55 t/ha below the conventional system, the net benefit falls to zero.

Conclusion of the cost-benefit analysis

From an operational perspective, switching to Mini-till, even without additional soil amendments, has a clear advantage: the technology saves UAH 3,824/ha in fuel, labour and machinery operating costs. The very small yield shortfall of 60 kg/ha compared with ploughing costs only UAH 420, leaving the farmer with UAH 3,404/ha in additional profit. To justify the higher cost of conventional ploughing, it would need to consistently produce 550 kg/ha more grain, which was not observed in practice.

However, the final economic model will be specific to each farm. Moving away from ploughing requires initial capital investment to upgrade the machinery fleet, including the purchase of heavy specialised seed drills for working through stubble and equipment for distributing mulch. The actual payback period therefore depends not only on operating savings, but also on the cost of new machinery and the scale of the farm's land bank.

2.5. Risks to watch

Agronomic risks

- **Higher weed pressure:** the absence of soil inversion through ploughing encourages weed seeds to accumulate in the upper soil layer, potentially requiring stronger herbicide protection.
- **Phytosanitary pressure:** crop residues on the soil surface can act as a reservoir for pathogens and pests, increasing the risk of infection in subsequent crops.
- **Temperature regime:** the mulch layer slows soil warming in spring, which may delay the sowing window for spring crops.

Operational risks

- **Technical requirements:** the system requires specialised heavy seed drills capable of cutting through stubble and high-quality crop-residue choppers.
- **Staff skills:** modern precision seeding systems, particularly for Strip-till, require a high level of training among machinery operators and engineering staff.
- **Narrow operational window:** sowing becomes more dependent on weather conditions, including the risk of excessive soil moisture beneath mulch.

Financial risks

- **High initial CAPEX:** significant one-off capital investment may be required to upgrade the machinery fleet, including the purchase of Mini-till/Strip-till combinations.
- **Transition-period cash-flow gap:** there is a risk of a temporary 5-10% decline in yield during the first 2-3 years of transition while the soil recovers its natural structure.
- **Higher crop-protection costs:** fuel savings may be partly offset by increased expenditure on glyphosate and other crop-protection products.

Common mistakes

01

Ignoring the plough pan: switching to Mini-till/Strip-till without first carrying out deep loosening and removing compaction created by years of ploughing.

02

Poor residue management: uneven distribution of straw from the previous crop, leading to uneven emergence and increased disease development.

03

Switching too much too quickly: introducing the new technology across 100% of the land bank immediately instead of testing it gradually on individual fields.

04

Copying a template approach: applying the technology without adapting it to the farm's specific soil type, crop rotation and microclimate.

2.6. Putting it to the test

Recommended trial approach: use a gradual, adaptive transition. Select a level field without a pronounced plough pan or severe perennial rhizomatous weed infestation. Before establishing the trial, remove any existing soil compaction, for example with a subsoiler, and level the surface.

Trial area: 1-10 ha, or one standard representative field, accounting for no more than 5-10% of the farm's total area under the selected crop in order to minimise financial risk.

Control: an adjacent plot within the same field, or a neighbouring field with an identical soil type and previous crop, managed using the farm's usual conventional intensive technology, including ploughing.

Trial duration: at least 3-4 years, covering one full crop rotation. Conclusions based on a single year are not sufficiently meaningful because restoration of natural soil structure, mulch accumulation and microbiome stabilisation take several seasons.

What to measure

01

Economic and operational indicators: actual diesel consumption (l/ha), machinery operating hours, labour costs and the final cost of producing one tonne of output.

02

Agronomic indicators: field emergence, crop-development dynamics, weed pressure, phytosanitary condition of the crop and harvested yield (t/ha).

03

Soil condition: changes in soil density or hardness (MPa or g/cm³), plant-available moisture during critical growth stages and the rate of crop-residue decomposition.

The full trial procedure is provided in Module 6: 'How to run a low-risk trial on your farm'.

2.7. The bottom line

Minimum tillage is worth considering if:

01

You want to substantially reduce diesel expenditure and lower production costs

02

The farm faces a shortage of qualified machinery operators and needs to reduce the number of field operations

03

Your fields are in an area with limited rainfall and conserving moisture through crop residues (mulch) is critically important

04

You are ready to optimise your machinery fleet and move towards multifunctional implements

The decision should be considered carefully if:

01

There is a pronounced plough pan or severe soil compaction in the fields, requiring deep loosening before transition

02

The fields are heavily infested with perennial rhizomatous weeds and herbicide control would cost more than ploughing

03

The farm operates on heavy, poorly drained soils that warm and dry slowly beneath mulch in spring

04

The business currently lacks available capital or access to finance for specialised heavy seeding equipment

Economic viability: The technology is highly effective and economically justified. Immediate savings in direct operating costs, up to UAH 3,824/ha on fuel, labour and machinery wear, create a substantial financial 'safety cushion'. From the first season, this fully offsets the risk of a modest decline in yield. The technology increases net marginal profit and remains at least break-even compared with ploughing even with a yield loss of 0.46-0.63 t/ha, depending on the technology and crop.

Optimal next step: Carry out a field audit, including measuring soil hardness with a penetrometer to identify any plough pan; select one representative field; and allocate a 10-50 ha trial area for the next season. To avoid the risk of purchasing new machinery during the testing phase, the best option is to hire a contractor with a modern Mini-till or Strip-till seeding combination to carry out trial sowing and compare the results with your baseline technology.

3.1. Biological products, explained

What are biological products?

Biological products are specially developed environmentally safe products based on living beneficial microorganisms, including bacteria and fungi, or products of their activity. Think of them as a type of 'probiotic' for the soil and plants. Rather than acting like harsh chemicals, they reproduce natural ecosystem processes. Once applied to the soil or leaves, these microorganisms begin to multiply actively, displacing harmful pathogens, helping plants access otherwise unavailable nutrients and stimulating plant immunity. They are a natural tool that can help farmers produce healthy crops while restoring depleted soils.

Which products and approaches do we consider?

The practices covered in this guide use an integrated approach involving several groups of products from a Ukrainian manufacturer:

Mycofriend: a mycorrhiza-forming product based on *Glomus fungi*. These fungi penetrate plant roots and form a mutualistic symbiosis. They act like a vast additional root network, dramatically increasing the surface area available for water and micronutrient uptake.

Azothelp K: a growth biostimulant. It contains nitrogen-fixing bacteria that can capture nitrogen from the atmosphere and convert it into a form the plant can use, providing a natural source of nutrition.

Groundfix: a phosphorus-potassium mobilisation product. Based on *Bacillus bacteria*, it acts as a biological solubiliser. It breaks down locked, unavailable mineral compounds of phosphorus and potassium in the soil and converts them into soluble forms that roots can absorb readily.

Ecoster (standard and detox): a complex biological decomposer. It contains powerful bacterial strains and *Trichoderma fungi*. It acts as a field 'sanitation' tool, rapidly breaking down tough stubble, neutralising accumulated toxins and pesticide residues and even chemically binding heavy metals to make them safer.



Picture 7. Researcher of the UkrNDIPVT performing laboratory analysis.

Liposam: a natural bio-adhesive. It is an exopolysaccharide substance that creates a protective elastic film on leaves. It retains moisture, helps prevent other products being washed off by rain and protects living bacteria from damaging solar ultraviolet radiation.

What problems can they help solve?

- **Soil degradation and depletion:** they help restore the soil's natural porous structure, friability and biological activity that may have been lost through intensive mechanical tillage.
- **Disease build-up:** they suppress soil-borne pathogens, such as Fusarium and root-rot pathogens, which accumulate on crop residues in short rotations.
- **Nutrient lock-up:** they address situations where essential macronutrients, including phosphorus and potassium, are physically present in the soil but locked in mineral salt forms that roots cannot access.
- **Chemical contamination (phytotoxicity):** they can help reduce residues of aggressive herbicides and neutralise heavy metals, which is particularly relevant for damaged land.
- **Moisture shortages:** they can improve plant drought tolerance by retaining moisture through bacterial exopolysaccharides and extending the root system through fungal mycelium.

Main potential benefits

01 Savings on mineral fertilisers: because bacteria can mobilise phosphorus and fix atmospheric nitrogen, farmers may be able to significantly reduce application rates of expensive synthetic fertilisers.	02 Higher yields: they can support strong early growth and plant development, potentially translating into additional grain output per hectare.
03 Improved product quality: they can increase thousand-seed weight and protein accumulation in grain, improving quality grade and market value.	04 Long-term ecosystem recovery: regular use can support humus accumulation and help restore the soil's ability to self-regulate without harming the environment.
05 Synergy with modern technologies: biological products fit well within conservation-agriculture systems such as Mini-till and No-till, where crop residues on the surface require managed decomposition.	

3.2. Finding the right fit

They may be suitable if:

01 You use conservation tillage such as Mini-till or No-till and large amounts of crop residues remain on the field, which need to be converted quickly into natural fertiliser rather than becoming a reservoir for disease
--



02

Your soils are depleted and compacted and have lost their natural porosity after repeated passes by heavy machinery

03

Laboratory analysis shows high levels of phosphorus and potassium in the soil, but they are present in locked forms unavailable to roots

04

You want to reduce the use of expensive synthetic fertilisers by partly replacing them with natural nitrogen fixation and nutrient mobilisation

05

Your crop rotation is too short, for example alternating sunflower and wheat, leading to rapid accumulation of root-rot pathogens in the soil

The decision should be considered carefully if:

01

Your fields are in an area of extreme drought. Microorganisms are living organisms and need at least some soil moisture to become active and reproduce

02

Your soil pH is extremely low, below 5.0, or strongly alkaline. Under such conditions, beneficial microorganisms may struggle to establish

03

You do not have the technical or logistical capacity to spray in the evening, at night or in cloudy conditions, because direct solar ultraviolet radiation can rapidly kill living bacterial cells

04

You are not prepared to wait and expect an 'instant' result. Biological approaches act more slowly than chemical ones because they involve building an entire microbial network over time

They may be unsuitable if:

01

You use aggressive broad-spectrum chemical fungicides continuously and intensively, as these may kill both harmful organisms and the beneficial microflora being introduced

02

Your tank mixes regularly contain inorganic copper-based products, which are directly toxic to living beneficial microbes

03

You plan to prepare working solutions using untreated chlorinated tap water, as chlorine acts as a strong sterilising agent and can kill the bacteria

04

Your farm's operating schedule does not allow stubble-decomposer products to be incorporated into the soil within 1-3 days after spraying

05

You plan to apply the products at temperatures below +5 C or above +30 C, when living organisms either become dormant or suffer severe heat stress

Table 4. Quick farm assessment

QUICK ASSESSMENT:

Are biological products suitable for your farm?

A few questions will tell you!

Tick the column that best describes your situation.

Nº	Question	Yes	Partly	No
1	 Do you use minimum tillage (Mini-till/No-till) or retain crop residues on the field?	☐	☐	☐
2	 Is there sufficient soil moisture during application?	☐	☐	☐
3	 Can you apply without prolonged heat, strong sun or drought?	☐	☐	☐
4	 Are you ready to avoid simultaneous use of incompatible chemical products?	☐	☐	☐
5	 Can you apply the product at the timing and in the manner recommended by the manufacturer?	☐	☐	☐
6	 Can you follow the recommended rate and storage conditions?	☐	☐	☐
7	 Can you run a small trial plot before large-scale application?	☐	☐	☐

RESULT

Count how many times you answered "Yes".

5-7
Great!

Biological products suit your system well. You can start with a small trial.

3-4
Potential, but adjustments needed.

Check moisture, timing and compatibility.

0-2
Conditions are not yet suitable.

Adjust conditions first or choose another approach.

3 KEY SUCCESS FACTORS

Moisture
Microorganisms need water to remain active.

Right timing
Avoid strong sun and heat during application.

Compatibility
Check compatibility with fungicides, insecticides and other products.

Healthy soil - stable harvest!



3.3. Evidence from the field

Our trial

- **Location:** Doslidnytske settlement, Bila Tserkva Raion, Kyiv Oblast (trial fields of the L. Pohorilyi UkrNDIPVT).
- **Year:** 2026
- **Crops:** spring barley (Lexi variety) and spring wheat (Likamero variety).
- **Products and application rates:** Mycofriend - 200 g/ha; Azothelp K - 0.5 l/ha; Liposam - 0.25 l/ha.
- **Application method and timing:** pre-sowing seed treatment with Mycofriend and foliar spraying at the flag-leaf stage, BBCH 37, using Azothelp K together with Liposam.
- **Control:** adjacent plots with identical tillage technologies but with no biological products applied.
- **Indicators measured:** soil density, moisture retention, pH, organic matter and NPK content, field emergence, crop-development dynamics including height and tillering, biological yield, grain-quality indicators and overall economic indicators.

Table 5. Main results of the biologicals trial

Indicator	Practice	Spring wheat (value with biological products / effect of biological products)	Spring barley (value with biological products / effect of biological products)
Field emergence, %	Conventional ploughing	90,1 / +0,1	85,0 / -6,0
	Mini-till (Ukrainian)	87,2 / +0,2	84,4 / -3,6
	Mini-till (foreign)	90,0 / +2,5	87,5 / +4,5
	Strip-till	92,7 / +7,0	82,8 / -3,4
Plant development:			
Height at wax-ripeness stage (16.07.2026), cm	Conventional ploughing	69,7 / -1,5	54,5 / +2,4
	Mini-till (Ukrainian)	72,3 / -1,8	55,4 / +2,0
	Mini-till (foreign)	69,3 / -6,4	53,5 / +0,6
	Strip-till	71,9 / -3,9	54,9 / +2,4
- Total tillering	Conventional ploughing	2,87 / +1,07	3,13 / +0,40
	Mini-till (Ukrainian)	2,40 / +0,20	2,87 / +0,20
	Mini-till (foreign)	2,47 / +0,54	3,07 / +0,14

Indicator	Practice	Spring wheat (value with biological products / effect of biological products)	Spring barley (value with biological products / effect of biological products)
	Strip-till	1,67 / -0,26	2,73 / +0,40
- Productive tillering	Conventional ploughing	2,87 / +1,07	3,13 / +0,46
	Mini-till (Ukrainian)	2,40 / +0,27	2,87 / +0,54
	Mini-till (foreign)	2,47 / +0,54	2,87 / +0,27
	Strip-till	1,67 / -0,26	2,53 / +0,46
- Ear length, cm	Conventional ploughing	7,42 / +0,80	6,42 / -0,14
	Mini-till (Ukrainian)	7,20 / +0,22	6,67 / +0,43
	Mini-till (foreign)	7,00 / -0,36	6,56 / +0,32
	Strip-till	6,51 / -0,49	6,18 / +0,78
Biological yield, t/ha	Conventional ploughing	5,56 / +0,42	5,52 / +0,23
	Mini-till (Ukrainian)	5,39 / +0,27	5,33 / +0,28
	Mini-till (foreign)	5,10 / +0,40	5,58 / +0,40
	Strip-till	5,17 / +0,24	5,51 / +0,39
Grain quality (protein, %)	Conventional ploughing	12,8 / +1,7	12,4 / +1,2
	Mini-till (Ukrainian)	15,3 / +1,2	11,9 / +0,7
	Mini-till (foreign)	14,0 / +1,5	12,0 / +0,5
	Strip-till	15,1 / +0,9	11,5 / +0,5

Analysis of the results showed a consistently positive effect of biological products on the productivity and grain quality of both spring crops under all tillage systems, with a stable increase in harvested yield of 0.21-0.39 t/ha and a substantial rise in protein content, up to +1.7 percentage points in wheat and +1.2 in barley. At the same time, crop biometric responses to the stimulants were crop-specific: in wheat, field emergence generally improved while plant height declined slightly, which can support lodging resistance; in barley, emergence more often declined, but productive tillering was strongly stimulated. Despite an equal increase in production costs across all technologies of approximately UAH 673/ha, the combined improvement in yield components and premium grain quality supports the case for integrating biological products. The strongest quality response was recorded under conventional ploughing and Ukrainian Mini-till.

What does the broader academic evidence from international and Ukrainian experience show?

- **Reduced dependence on synthetic nitrogen fertilisers.** Associative and free-living soil bacteria can fix atmospheric nitrogen and convert it into plant-available forms, allowing mineral fertiliser rates to be optimised without loss of productivity.^{10 11}
- **Greater phosphorus availability.** Specific strains of microorganisms, known as phosphate mobilisers, release organic acids and phosphatase enzymes that transform insoluble soil phosphates into water-soluble forms readily absorbed by roots.¹²
- **Stimulation of root-system development.** Plant-growth-promoting rhizobacteria synthesise phytohormones, including auxins, gibberellins and cytokinins, which stimulate active root branching, root-hair formation and expansion of the plant's total absorptive area.¹³
- **Improved resistance to drought and stress.** Bacteria that produce the ACC deaminase enzyme can break down the precursor of ethylene, a hormone associated with ageing and stress, thereby protecting plants from premature wilting under moisture shortages, extreme temperatures or soil salinity.¹⁴
- **Biological control of phytopathogens.** Beneficial microflora act as natural antagonists of disease-causing organisms. They synthesise antibiotics, lytic enzymes and siderophores, compounds that bind iron and deprive pathogens of nutrients, effectively suppressing root rots and fungal infections.¹⁵
- **Improved soil structure and water-holding capacity.** Soil microorganisms release exopolysaccharides that act as a biological 'glue'. They bind soil microparticles into water-stable macroaggregates, helping prevent erosion and improve the soil's ability to retain moisture.¹⁶
- **Expansion of the nutrient-uptake zone through mycorrhiza.** Symbiosis with arbuscular mycorrhizal fungi can increase many times over the effective volume of soil from which a plant can obtain resources. This is particularly important for less mobile nutrients such as zinc, copper and phosphorus.¹⁷
- **Greening production and restoring fertility.** Systematic use of microbiological products can gradually restore the natural soil microbiome degraded by intensive tillage and chemical inputs, supporting a shift towards regenerative agriculture and a lower carbon footprint.¹⁸

¹⁰ Parkhomenko, M. M. (2025). Productivity of agrocenoses in crop cultivation under different fertilisation and inoculation systems. *Agricultural Microbiology*, (42), 30–43. <https://doi.org/10.35868/1997-3004.42.30-43> <https://doi.org/10.35868/1997-3004.42.30-43>

¹¹ Volkohon, V. (2011). Biological soil reclamation. Traditional and new approaches. *Agricultural Microbiology*, 13, 7–22. <https://doi.org/10.35868/1997-3004.13.7-22> <https://doi.org/10.35868/1997-3004.13.7-22>

¹² Kurdys, I. K. Introduction of Microorganisms into Agroecosystems. Kyiv: Naukova Dumka, 2010. 254 pp.

¹³ Glick, B. R. (2012) 'Plant growth-promoting bacteria: Mechanisms and applications', *Scientifica*, 2012, 963401. <https://doi.org/10.6064/2012/963401>

¹⁴ Glick, B. R. (2014) 'Bacteria with ACC deaminase can promote plant growth and help to feed the world', *Microbiological Research*, 169(1), 30–39. <https://doi.org/10.1016/j.micres.2013.09.009>

¹⁵ Compant, S., Duffy, B., Nowak, J., Clément, C. and Barka, E. A. (2005) 'Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action, and future prospects', *Applied and Environmental Microbiology*, 71(9), 4951–4959. <https://doi.org/10.1128/AEM.71.9.4951-4959.2005>

¹⁶ Costa, O. Y. A., Raaijmakers, J. M. and Kuramae, E. E. (2018) 'Microbial extracellular polymeric substances: Ecological function and impact on soil aggregation', *Frontiers in Microbiology*, 9, 1636. <https://doi.org/10.3389/fmicb.2018.01636>

¹⁷ Smith, S. E. and Read, D. J. (2008) *Mycorrhizal Symbiosis*, 3rd edn. Academic Press. <https://doi.org/10.2136/sssaj2008.0015br>

¹⁸ Bashan, Y., de-Bashan, L. E., Prabhu, S. R. and Hernandez, J.-P. (2014) 'Advances in plant growth-promoting bacterial inoculant technology: Formulations and practical perspectives (1998–2013)', *Plant and Soil*, 378(1–2), 1–33. <https://doi.org/10.1007/s11104-013-1956-x>

Oleksandr Moroz: from scepticism to practical experience with biological approaches



Oleksandr Moroz, chief agronomist at Terezine in Kyiv Oblast, which has a land bank of 2,630 ha, is now a supporter of a balanced combination of chemical and biological products. Earlier in his career, while working for international chemical companies, he was sceptical about biological products.

Practice changed his view. The company actively introduced biological solutions and over time Oleksandr Moroz saw the results directly in the fields. Today, for him biological products are not an alternative for its own sake, but a tool that should be selected for a specific task and combined with other elements of the production system.

'At first, I did not really believe in biological products. But when I saw the results in my own fields, my attitude changed,' says Oleksandr Moroz, chief agronomist at Terezine.

Terezine specialises in livestock production and makes active use of organic fertilisers. It is therefore important for the farm not only to supply plants with nutrients, but also to make those nutrients more available and maintain biological activity in the soil.

To improve soil fertility, the farm uses Groundfix, which helps increase the availability of phosphorus and potassium compounds to plants. Biological products are also used in crop-production programmes: Mycofriend for treating winter cereal and maize seed, and bio-inoculants for pre-sowing treatment of soybean and pea seed. Sclerocide is used to protect crops from white mould, and the farm assesses its effectiveness positively.

According to Oleksandr Moroz, biological products have increased yields by up to 0.5 t/ha in sunflower and 0.2 t/ha in soybean.

A separate area is biological crop protection in protected vegetable production and orchards, which the business has used for four years. The farm has developed practical experience with biological solutions that have become part of its production technology.

At the same time, Terezine does not stop with already proven solutions. New biological products are tested in small-plot trials before a decision is made on their use in commercial production. This allows the agronomist to assess a product based not on the manufacturer's claims, but on how it performs under the farm's specific conditions.

Oleksandr Moroz's experience shows that biological approaches do not necessarily mean abandoning chemicals altogether. The greatest effect comes from a sensible combination of tools, including organic fertilisers, biological products and chemical protection, accompanied by continuous testing of their effectiveness.

For Terezine, biological products are no longer a matter of belief. They are a matter of practice: test them, observe the result and retain in the production system what genuinely works.

3.4. The economics of biological products

Cost of the product and its application: UAH 673.3/ha

Impact on revenue: +UAH 1,440 to +UAH 2,340/ha

Indicative net benefit: +UAH 766 to +UAH 1,667/ha

Yield increase required to break even: 100-110 kg/ha, depending on the grain purchase price, to fully recover the cost of the product and its application.

Table 6. Cost-benefit analysis of biological-product use on spring wheat and barley (per 1 ha)

Indicator	Practice	Spring wheat (value with biological products / effect of biological products)	Spring barley (value with biological products / effect of biological products)
Harvested yield, t/ha	Conventional ploughing	5,10 / +0,30	5,14 / +0,24
	Mini-till (Ukrainian)	4,99 / +0,25	5,09 / +0,26
	Mini-till (foreign)	4,74 / +0,31	5,27 / +0,39
	Strip-till	4,72 / +0,21	5,14 / +0,29
Production costs, UAH/ha (difference = cost of biological products)	Conventional ploughing	30 348,5 / +673,3	27 853,3 / +673,3
	Mini-till (Ukrainian)	26 524,2 / +673,3	24 068,8 / +673,3
	Mini-till (foreign)	26 905,1 / +673,3	24 409,9 / +673,3
	Strip-till	27 115,5 / +673,3	24 620,3 / +673,3
Revenue, UAH/ha (assumed price: wheat - UAH 7,000, barley - UAH 6,000)	Conventional ploughing	35 700,0 / +2 100,0	30 840,0 / +1 440,0
	Mini-till (Ukrainian)	34 930,0 / +1 750,0	30 540,0 / +1 560,0
	Mini-till (foreign)	33 180,0 / +2 170,0	31 620,0 / +2 340,0
	Strip-till	33 040,0 / +1 470,0	30 840,0 / +1 740,0
Additional net profit from biological products, UAH/ha	Conventional ploughing	Effect: +1,426.7	Effect: +766.7
	Mini-till (Ukrainian)	Effect: +1,076.7	Effect: +886.7
	Mini-till (foreign)	Effect: +1,496.7	Effect: +1,666.7
	Strip-till	Effect: +796.7	Effect: +1,066.7

Break-even analysis

To fully recover investment in biological products, UAH 673.3/ha, a minimum yield increase of 0.10 t/ha for wheat and 0.11 t/ha for barley is sufficient. Because the actual increase in the trial ranged from 0.21 to 0.39 t/ha, the break-even threshold was comfortably exceeded in every treatment. From the perspective of tillage systems, the production-cost savings generated by Mini-till provide a strong financial safety cushion: the technology remains more profitable than ploughing even if yields fall by 0.55 t/ha for wheat or 0.63 t/ha for barley.

The economic model demonstrates a high degree of resilience to market fluctuations:

- **Higher fuel prices:** if diesel becomes more expensive, the financial advantage of Mini-till and Strip-till systems increases further because they save 41-48 litres of fuel per hectare.
- **Lower grain prices:** even if grain purchase prices fall by 20%, to UAH 5,600/t for wheat and UAH 4,800/t for barley, biological products remain profitable because the additional yield comfortably exceeds the basic application cost.

Combining resource-efficient tillage technologies, including Mini-till and Strip-till, with biological approaches is economically justified and strategically sound. Moving away from conventional ploughing reduces direct production costs by UAH 3,233-3,824/ha. Integrating biological products provides an additional profit multiplier: in all trial variants they recovered their cost and generated UAH 767-1,667/ha in additional net benefit. The highest combined economic performance for both crops was achieved by pairing Mini-till, using precision foreign seeding equipment, with biological products.

3.5. Risks to watch

Product quality and storage

Biological products contain living microorganisms. If they are left in the sun, overheated in a vehicle, frozen or stored beyond their shelf life, the bacteria can die. In that case, the farm will effectively be applying little more than 'coloured water'. Buy from trusted suppliers and strictly observe the required storage temperature.

Application and timing

Direct sunlight, particularly ultraviolet radiation, can kill beneficial microbes within minutes. The main risk is applying the product during the day in strong sun. To keep the bacteria alive and effective, spraying should be carried out in the evening, at night, at dawn or in cloudy weather.

Agronomic conditions

Microorganisms need moisture to become active. If a product is applied to completely dry, dusty soil during a prolonged severe drought, the bacteria will not be able to multiply and work effectively in the root zone. Biological products perform best in moist soil, including when applied ahead of rainfall or dew.

Financial risk

The financial risk itself is very low. The cost, around UAH 670/ha, is modest and can be recovered with a yield increase of only 100-110 kg/ha for cereals such as wheat or barley. The main financial risk is the unavoidable loss of this investment if the crop is completely destroyed by force majeure, such as extreme drought, hail or winterkill.

Common mistakes

01

Dirty sprayer: residues of aggressive chemical products, especially fungicides, in the tank can kill the living biological organisms.

02

Incorrect tank mixes: mixing biological products with incompatible chemicals without prior testing.

03

Preparing too early: diluting the product with water several hours before entering the field. The working solution should be prepared immediately before application.

04

Chlorinated water: using tap water with a high chlorine content, which is toxic to bacteria.

3.6. Putting it to the test

Recommended trial approach: use a side-by-side method. Allocate a small area and compare it with a control on the same field. For a first trial, 1-10 ha is sufficient, depending on the size of the farm and available machinery. Choose a plot that is typical for your farm and does not have problems with waterlogging, compaction, erosion or severe weed infestation. This helps ensure that the result reflects the effect of the product rather than unusual characteristics of the plot. Repeat the comparison over several years, as the effectiveness of biological technologies depends on weather, soil moisture, temperature and crop condition.

Trial treatment: part of the field where you apply the new practice, for example Mini-till, together with the biological product, while strictly following all technical requirements such as evening application, a clean sprayer and settled chlorine-free water.

Control without the product: a neighbouring plot in the same field with identical soil and the same previous crop. Sow the same variety on the same day, but use your normal conventional technology, for example ploughing, and apply no biological product. This is your baseline for comparison.

What to measure:

01

Agronomy: field emergence, phytosanitary condition including disease incidence, and final harvested yield (t/ha).

02

Soil condition: plant-available moisture reserves, changes in soil density and the rate of crop-residue decomposition.

03

Economics: actual fuel use (l/ha), machinery operating hours, additional product costs and the final cost of producing one tonne of grain on both plots.

The full trial procedure is provided in Module 6.

4.1. Biochar, explained

What is biochar?

Biochar is a stable, porous, carbon-rich material produced by heating organic waste, such as straw, crop residues, husks, wood or manure, with very limited oxygen. This process is called pyrolysis and takes place at temperatures from around 350 C to more than 800 C. Unlike ordinary ash, which is quickly washed out by water, biochar has a stable carbon structure that resists rapid decomposition and can remain in soil for hundreds of years. Its microporous structure allows it to act like a 'sponge': it stores moisture and nutrients effectively and creates a favourable habitat for beneficial soil microorganisms.

How is it applied?

Modern agronomy is moving away from applying tens of tonnes of biochar per hectare. Instead, lower-dose approaches of 1-5 t/ha are increasingly used, depending on soil type and the severity of soil problems. When combined with microbiological products, application rates may be as low as 10 kg/ha through localised placement. One of the most economically and technically sound approaches is to pre-mix biochar with organic fertilisers such as manure or compost. Biochar is added to the organic material at around 10% of dry matter and left for 3-4 weeks to ferment. During this time, its porous structure becomes 'charged' with nutrients. The prepared mixture is then applied with standard fertiliser spreaders and incorporated into the root zone.

What problems can it help solve?

- **Soil compaction:** because of its low density, biochar can help loosen heavy clay soils, reduce resistance and support root-system development.
- **Drought impacts:** biochar pores retain moisture during heavy rainfall and release it gradually to plants during dry periods, significantly reducing water stress.
- **Fertiliser leaching:** biochar can retain nitrogen, phosphorus and potassium in the root zone. This may allow farmers to reduce chemical fertiliser use by 15-20% without loss of productivity.
- **High acidity:** most biochars are alkaline. They act as a buffer, neutralising acidic soils and reducing the toxic effect of aluminium on plants.
- **Nitrogen losses:** biochar supports beneficial microflora, helping with atmospheric nitrogen fixation while reducing losses in the form of greenhouse-gas emissions.

Why should its impact be assessed over several seasons?

Unlike synthetic mineral fertilisers, which mainly act within a single season, biochar is a long-term improvement to the soil itself. Its benefits accumulate over time. In the first year after application, the effect may be moderate because the porous material is still absorbing nutrients. In subsequent seasons, its full potential becomes clearer as microbial colonies

develop in the pores, beneficial interaction with plant roots strengthens and soil structure improves. Research indicates that the largest yield increase can occur in the third year after application, a phenomenon often described as a 'legacy effect'.

Table 7. Quick assessment

4.3. Evidence from the field

Our trial

- **Location:** Doslidnytske settlement, Bila Tserkva Raion, Kyiv Oblast (trial fields of the L. Pohorilyi UkrNDIPVT).
- **Year:** 2026.
- **Crop:** spring barley (Lexi variety).
- **Soil:** deep, low-humus, medium-loam chernozem. Level terrain with an even microrelief.
- **Biochar type and quality:** wood biochar with an organic carbon content (Corg) of 61.6%. The material meets Class 1 quality requirements under the European Biochar Certificate, EBC version 10.4 (2024), and IBI Biochar Standards v.2.0, providing assurance that the amendment itself does not contain toxic tars or heavy metals.
- **Application scheme:** biochar applied at 5 t/ha before sowing and in combination with biological products (Mycofriend, Azothelp, Liposam).
- **Application method:** surface distribution of the material, followed by levelling with a BP-12 harrow and incorporation using an APOG-6 unit with a John Deere 6155M tractor. The trial was integrated into a Ukrainian Mini-till system.
- **Control:** a plot managed in the same way but without biochar or biological products.
- **Indicators measured:** agrochemical indicators including pH in water and salt extract, humus and available forms of macronutrients N, P and K; agrophysical indicators including soil density and plant-available moisture; soil microbiological analysis; and yield and product-quality indicators.

What did the trials show?

Table 8. Impact of biochar and biological products on soil indicators and yield

Indicator*	Practice (Ukrainian Mini-till)	Indicator value	Difference vs control (+/-)
Yield, t/ha	- control	4,83	-
	- biochar	5,21	+0,38 (+7,87%)
	- biochar + biological products	5,52	+0,69 (+14,29%)
Protein content in grain, %	- control	11,2	-
	- biochar	11,3	+0,10 (+0,89%)
	- biochar + biological products	14,0	+2,80 (+25,00%)
Soil pH (salt extract, 0-10 cm layer)	- control	7,4	-
	- biochar	7,5	+0,10 (+1,35%)
	- biochar + biological products	7,4	-
Humus	- control	3,53	-

Indicator*	Practice (Ukrainian Mini-till)	Indicator value	Difference vs control (+/-)
	- biochar	3,74	+0,21 (+5,95%)
	- biochar + biological products	3,71	+0,18 (+5,10%)
	- control	10,8	-
Hydrolysable nitrogen, mg/100 g (0-10 cm layer)	- biochar	12,9	+2,1 (+19,44%)
	- biochar + biological products	14,8	+4,0 (+37,04%)
	- control	25,2	-
Available phosphorus, mg/100 g (0-10 cm layer)	- biochar	27,8	+2,6 (+10,32%)
	- biochar + biological products	41,8	+16,6 (+65,87%)
	- control	32,5	-
Available potassium, mg/100 g (0-10 cm layer)	- biochar	39,5	+7,0 (+21,54%)
	- biochar + biological products	41,0	+8,5 (+26,15%)
	- control	1,23	-
Soil bulk density, g/cm³ (0-10 cm layer)	- biochar	1,20	-0,03 (-2,44%)
	- biochar + biological products	1,18	-0,05 (-4,07%)
	- control	20,9	-
Plant-available moisture, mm (0-40 cm layer)	- biochar	26,4	+5,5 (+26,32%)
	- biochar + biological products	26,0	+5,1 (+24,40%)
	- control	26,0	-

* Soil-condition indicators were measured at the end of the trial (05.08.2026).

Higher yield and grain quality: biochar alone increased yield by 7.87%, to 5.21 t/ha, while the 'biochar + biological products' treatment increased yield by 14.29%, to 5.52 t/ha. The combined treatment also had a major effect on quality: grain protein content increased by 25%, from 11.2% in the control to 14.0%.

Strong nutrient mobilisation (NPK): the largest synergistic effect was observed in nutrient availability. The treatment including biological products increased available phosphorus by 65.87%, hydrolysable nitrogen by 37.04% and available potassium by 26.15% compared with the control plot.

Higher moisture reserves and humus: in both biochar treatments the analysis showed a higher humus reading, by around 5–6%, but much of this represents the carbon contained in the biochar itself rather than newly formed humus; this carbon can remain in the soil for hundreds of years. Water retention also improved substantially: plant-available moisture in the 0–40 cm layer increased by 26.32% (+5.5 mm) under biochar alone and by 24.40% (+5.1 mm) under the combined treatment.

Main conclusion: biochar on its own performs well for moisture retention and provides a moderate yield increase. However, to realise the technology's full potential, particularly to substantially increase grain protein and release phosphorus and nitrogen locked in the soil, biochar is recommended for use in synergy with biological products.

What does the broader academic evidence show?

- **Higher yields:** analysis of research indicates that biochar increases crop yields by around 10% on average. The strongest positive agronomic effects are observed on degraded and acidic soils.¹⁹
- **Improved moisture retention:** biochar application increases the soil's capacity to retain plant-available water by more than 20% on average. This effect is particularly pronounced in coarse-textured soils when fine biochar fractions are used.²⁰
- **Reduced soil acidity:** most types of biochar can increase soil pH by around 6% on average. Biochar also increases soil buffering capacity, making it more resistant to further harmful acidification.²¹
- **Synergy with fertilisers:** combining biochar with mineral or organic fertilisers often performs better than fertiliser alone and delivers an average yield increase of 15%.²²
- **Optimising application rates:** localised root-zone application of biochar, at around 4 tonnes per hectare, combined with minimum-tillage technologies can produce a strong positive effect while substantially reducing material requirements.²³
- **Improved compost quality:** co-composting organic material with biochar helps retain significant quantities of nitrates in the finished substrate. Adding biochar as a bulking agent also successfully reduces ammonia losses during composting.²⁴
- **Lower greenhouse-gas emissions:** agricultural use of biochar clearly reduces nitrous oxide (N₂O) emissions from soils. This makes it one of the few solutions that both stores carbon and reduces emissions of other harmful gases.²⁵
- **Use as a feed additive:** adding biochar to animal feed, typically at around 0.3% of feed volume, can improve growth, blood indicators and overall disease resistance. It may also help reduce methane emissions from ruminants and bind toxins.²⁶

¹⁹ Schmidt, H.-P., Kammann, C., Hagemann, N., Leifeld, J., Bucheli, T. D., Sánchez Monedero, M. A. and Cayuela, M. L. (2021) 'Biochar in agriculture – A systematic review of 26 global meta-analyses', *GCB Bioenergy*, 13(11), 1708–1730. <https://doi.org/10.1111/gcbb.12889>

²⁰ Wei, B., Peng, Y., Lin, L., Zhang, D., Ma, L., Jiang, L., Li, Y., He, T. and Wang, Z. (2023) 'Drivers of biochar-mediated improvement of soil water retention capacity based on soil texture: A meta-analysis', *Geoderma*, 437, 116591. <https://doi.org/10.1016/j.geoderma.2023.116591>

²¹ Liu, S., Cen, B., Yu, Z., Qiu, R., Gao, T. and Long, X. (2025) 'The key role of biochar in amending acidic soil: Reducing soil acidity and improving soil acid buffering capacity', *Biochar*, 7(1), 52. <https://doi.org/10.1007/s42773-025-00432-8>

²² Ye, L., Camps-Arbestain, M., Shen, Q., Lehmann, J., Singh, B. and Sabir, M. (2020) 'Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls', *Soil Use and Management*, 36(1), 2–18. <https://doi.org/10.1111/sum.12546>

²³ Obia, A., Cornelissen, G., Martinsen, V., Smebye, A. B. and Mulder, J. (2020) 'Conservation tillage and biochar improve soil water content and moderate soil temperature in a tropical Acrisol', *Soil & Tillage Research*, 197, 104521. <https://doi.org/10.1016/j.still.2019.104521>

²⁴ Busch, F., Leal, O. dos A., Siebers, N. and Brüggemann, N. (2024) 'Biochar captures ammonium and nitrate in easily extractable and strongly retained form without stimulating greenhouse gas emissions during composting', *Journal of Environmental Quality*, 53(6), 1099–1115. <https://doi.org/10.1002/jeq2.20634>

²⁵ Zhong, L., Wang, P., Gu, Z., Song, Y., Cai, X., Yu, G., Xu, X. and Kuzyakov, Y. (2025) 'Biochar reduces N₂O emission from fertilized cropland soils: A meta-analysis', *Carbon Research*, 4(1), 31. <https://doi.org/10.1007/s44246-025-00198-5>

²⁶ Nair, P. S., P. S., S. M., Suresh, S., A. J., S., K., S., S., A. K., P. R., A., Krishnan, N., S., P., Chakraborty, S., Chopra, H., Akash, S., Amin, R., Dey, A., Alagawany, M., Chandran, D. and Dhama, K. (2023) 'Beneficial impacts of biochar as a potential feed additive in animal husbandry', *Journal of Experimental Biology and Agricultural Sciences*, 11(3), 479–499. [https://doi.org/10.18006/2023.11\(3\).479.499](https://doi.org/10.18006/2023.11(3).479.499)

FARMER STORY

Ruslan Dehtiarov: from Japanese experience to the Ukrainian field



Ruslan Dehtiarov is Chief Operating Officer of Baryshivska Grain Company, which cultivates around 57,000 ha across Kyiv, Cherkasy, Poltava and Chernihiv oblasts. One of the farm's challenges is managing problematic soils in Chernihiv Oblast, where acidity is higher, some nutrients have low availability and fertility must be maintained continuously.

The farm previously used periodic liming to correct acidity. Biochar offered a different approach: rather than a one-off adjustment to soil indicators, it involves applying a material that can remain active in the soil for many years. While liming has to be repeated depending on soil condition, biochar is considered a long-term investment in soil properties.

Ruslan Dehtiarov first became closely acquainted with the technology through the UNIDO project 'Green Industrial Recovery in Ukraine', involving Tromso Co., Ltd. As part of a Ukrainian delegation, he visited Japan, where he observed technology for producing biochar from agricultural waste and the practical results of its use. The possibility of converting agricultural waste into a resource for soil restoration was one of the aspects that attracted his attention.



Pictures 8, 9 and 10. Ruslan Dehtiarov during a training visit in Japan, Tromso Co., Ltd: practical application of biochar.

In 2026, the farm took its first practical step: on a 1 ha soybean plot with sandy, low-fertility soil, it applied Ukrainian-produced biochar at a rate of 10 t/ha. This remains an experimental-scale application, as the farm understands that biochar should not be expected to produce fundamental changes in the first season. Its value lies in its long-term effect. Baryshivska Grain Company therefore treats this trial not as an attempt to obtain a quick yield increase, but as an investment in the future condition of the soil. The coming years will show how effective biochar is on these specific soils and whether the technology can be scaled to larger areas.

For a farm of this scale, the trial is also an opportunity to test the technology under real production conditions and use its own observations to determine where biochar can deliver the greatest effect.

4.4. The economics of biochar

The economic assessment of biochar has fundamental features because, unlike conventional mineral fertilisers or biological products, biochar is a long-term capital investment in the soil (CAPEX). The applied material does not decompose within one season and can remain active in the agroecosystem for decades or centuries. For this reason, first-year economic performance should be interpreted cautiously as **an interim result**.

Initial biochar cost: UAH 20,000/t.

The initial investment will depend on soil type and condition and the selected application rate.

First-year costs and economics: spring barley example

Table 9. Cost-Benefit Analysis (per hectare)

Indicator	Control	Biological products	Biochar (5 t/ha)	Combined treatment
Additional costs (full first-year biochar cost and application), UAH/ha	0	673	101 801	102 474 (101 801 + 673)
Increase in harvested spring barley yield, t/ha	Baseline (4.83 t/ha)	+0.26 t/ha	+0.38 t/ha	+0.69 t/ha
Additional revenue (grain price UAH 6,000/t), UAH/ha	-	+1 560	+2 280	+4 140
Net economic effect (year 1), UAH/ha	-	+887	-99 521	-98 334 (interim result before the legacy effect develops)
Benefit-cost ratio (B/C)	-	2.32	0.02	0.04 (requires a long payback period)

- **First-year cost basis:** The calculation uses the full first-year cost of biochar and its application: UAH 100,000/ha for biochar at 5 t/ha, plus UAH 1,801/ha for spreading and incorporation, for a total of UAH 101,801/ha. Biological products add UAH 673/ha for seed treatment and one foliar application.

- **Combined-treatment economics:** With biological products included, total additional expenditure in the combined treatment is UAH 102,474/ha in the first year. Biochar alone increased harvested spring barley yield by 0.38 t/ha, equal to UAH 2,280/ha in additional revenue, while the combined biochar + biological-products treatment increased yield by 0.69 t/ha, equal to UAH 4,140/ha at a grain price of UAH 6,000/t, while protein content rose to 14.0%.
- **First-year payback:** Because first-year direct revenue covers only around 2–4% of these costs, the first-year net economic effect remains negative, at UAH -98,334/ha for the combined treatment. This confirms that on low-margin grain crops such as wheat and barley, purchased biochar does not pay back within one season from grain revenue alone.
- **Long-term effect and the legacy effect:** Because the first-year trial results are consistent with international evidence, both yield and economic returns may increase in subsequent seasons. As the microbiome stabilises and the legacy effect develops, international evidence indicates that yield gains in years 2–3 may reach around 10–15%, compared with about 8% in the first year. For low-margin cereals, however, this only partly offsets the initial capital cost, and full payback still requires a longer time horizon or a shift to higher-margin crops.

Potential monetisation of removed carbon through carbon-removal credits may also support payback, although administration of such projects at individual-farm level remains demanding.

- Alternative: microdoses and higher-margin crops.
- Given the logistical and application challenges associated with high rates of 3–5 t/ha, experts recommend considering microdose approaches, for example integration into organic fertilisers or localised root-zone application.²⁷

For higher-margin crops, including vegetables, berries and intensive orchards, the economics are fundamentally different. Initial investment can be recovered over the first seasons not only through yield gains of 10–15%, but also through better plant survival during drought and improved marketable quality.

Yield economics: when and why it can pay

If you grow a high-margin crop with planned revenue of, for example, UAH 600,000 per hectare, a 10–15% increase in yield or marketable quality attributable to biochar could generate an additional UAH 60,000–90,000 in the first year. This covers around 60–90% of the initial investment of UAH 101,801/ha at a 5 t/ha application rate including incorporation, so the investment may pay back over 1–2 seasons even without carbon-credit revenue.

Because biochar does not readily decompose and can remain in soil for hundreds of years, the benefit can continue in subsequent seasons as additional net profit while also allowing potential savings on fertiliser use.

The financial model is sensitive to three factors:

- **Biochar price:** the decisive factor. Producing biochar on-farm from waste can shorten the payback period substantially, while purchasing a premium product, for example at UAH 40,000/t, can extend it by many years.

²⁷ Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G., Rutherford, D., Sparrevik, M., Hale, S., Obia, A. and Mulder, J. (2013) 'Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia', *Agronomy*, 3(2), 256–274.
<https://doi.org/10.3390/agronomy3020256>

- **Crop margin:** growing higher-value crops such as oilseeds, soybean, vegetables and blueberries generates a much larger cash return from a yield increase than basic cereals.
- **Mineral fertiliser prices:** the more expensive conventional fertilisers become, the more valuable biochar's ability to retain nutrients in the soil becomes.

Investment in biochar is justified where a farm operates on problematic soils, grows medium- or high-margin crops and owns the land or holds it under a long-term lease. It is riskier where a farmer grows low-margin crops on high-quality chernozem or operates under short-term leases of one to two years, because there may not be enough time to recover the capital cost.

4.5. Risks to watch

Biochar quality risks. Failure to follow proper pyrolysis technology can produce an ineffective product. If the carbon balance is poor or the feedstock has an excessively high mineral content, such as poultry litter, the final material may have low porosity and fail to deliver the expected effect.

Contamination risks. If chemically treated wood is used as feedstock or the temperature regime is not properly controlled, biochar may contain heavy metals and carcinogenic compounds. To manage this risk, farmers should require evidence that the material complies with recognised European certification schemes, such as EBC, which provide assurance of product safety.

Transport costs. Biochar has an extremely low bulk density. Transporting this light but bulky material over distances of more than 150 km can often make the logistics uneconomic.

Application challenges. Dry, untreated biochar is highly prone to dusting. During mechanised spreading in windy conditions, a farmer can lose a significant share of the material and create unsafe conditions for machinery operators. Application should therefore use dampened biochar or compost-based mixtures.

Impact of land tenure. Because the full agronomic return may emerge only in the third year, applying biochar on land held under a short-term lease of less than three years creates a risk that another tenant will capture the benefits of the investment.

Other potential risks. Biochar has a high sorption capacity and can therefore partly bind and neutralise soil-applied herbicides, reducing weed-control effectiveness. This may require adjustments to application rates or a shift towards post-emergence herbicides.

4.6. Putting it to the test

To minimise risk, farmers are advised to run a localised strip trial:

1. **Preparation:** purchase 1-2 tonnes of certified biochar, with the final rate depending on soil type and the severity of the soil problem. Mix it with organic material, such as manure or compost, at a ratio of 1:10 and leave it for 3-4 weeks to ferment.
2. **Site selection:** choose the least productive part of the field, for example an area prone to drought, with light sandy soil or heavy loam.
3. **Establish the strips:**
 - *Control strip:* apply the standard fertiliser rate using the farm's normal technology.

- *Trial strip: apply the prepared biochar mixture while reducing the mineral nitrogen fertiliser rate by 15–20%.*
- 4. **Monitoring:** throughout the season, observe plant response, especially during drought, and record any difference in yield at harvest.
- 5. **Capture the legacy effect:** the most important step is to keep the trial areas clearly marked and monitor them for the following two years *without additional biochar* application. Decide whether to scale the practice across the farm only after assessing the long-term effect.

The full trial procedure is provided in Module 6.

RESTORING WAR-DAMAGED SOILS



5.1. Safety first

Restoring land damaged by war is impossible without prior humanitarian demining and removal of explosive hazards.

Before beginning any restoration work:

- Obtain an official document from the relevant state authorities, for example the State Emergency Service of Ukraine (SESU), confirming full humanitarian clearance of the site and removal of unexploded ordnance (UXO) and machinery debris.
- Carry out a comprehensive agrochemical analysis to determine the degree of physical degradation, such as compaction caused by heavy tracked machinery, loss of humus and the condition of the soil microbiome.
- A toxicological soil assessment is mandatory to detect heavy metals, particularly lead, zinc, cadmium and copper, as well as petroleum residues and explosive compounds such as TNT and RDX. Concentrations are typically highest at explosion sites and locations where machinery has burned.
- If hyperaccumulator plants such as rapeseed, sunflower, mustard or lupin have been used to clean the field, the harvested biomass must be tested for contaminants and disposed of in a controlled manner to prevent heavy metals entering the food chain.
- If biochar is used as a soil amendment, apply only certified material, for example material complying with the European Biochar Certificate (EBC), to avoid secondary contamination by carcinogenic polycyclic aromatic hydrocarbons (PAHs) or heavy metals from poor-quality feedstock.

Note: Do not begin work if the site does not have an official demining certificate, if destroyed military equipment remains in the field and is generating very high contamination levels, or if laboratory results do not confirm that soil toxicity is compatible with safe agricultural use.

5.2. Diagnosing the damage

Step 1. Has the area been officially confirmed as safe?

1. Submit a request to SESU or a certified mine-action operator to survey the site.
2. Wait for non-technical survey and, where necessary, technical humanitarian demining to be completed.
3. Obtain an official act or certificate confirming full clearance of the area from mines, unexploded ordnance (UXO) and remnants of destroyed machinery. No field work should begin without this document.

Step 2. Has the soil been tested?

Use an accredited laboratory for a comprehensive agrochemical, toxicological and physical assessment. Sampling should focus on the highest-risk areas, including explosion epicentres,

craters and places where heavy armoured vehicles burned. The assessment should evaluate soil compaction, humus loss and the condition of the soil microbiome.

Step 3. Has contamination been detected?

Laboratory results should be compared with the applicable maximum permissible concentrations. Particular attention should be paid to heavy metals, including lead, cadmium, zinc and copper, as well as petroleum residues and explosive compounds such as TNT and RDX. Experience shows that at locations where machinery has been destroyed, concentrations of these contaminants can exceed permitted levels by tens of times, creating an extremely high level of risk.

Step 4. Is agricultural production considered safe?

If maximum permissible concentrations of heavy metals or organic contaminants are exceeded, growing food or feed crops is unsafe. Toxins and carcinogens can be absorbed by plant roots and enter the food chain, posing risks to human and animal health. If indicators remain within permitted levels, the site can be returned gradually to agricultural use, with priority given to restorative practices.

Step 5. What type of restoration may be appropriate?

The choice of method depends on the type of degradation:

- **For removing heavy metals and nitrates:** use phytoremediation, including hyperaccumulator crops such as rapeseed, sunflower, mustard or lupin, followed by controlled harvesting and safe disposal of the biomass.
- **For breaking down petroleum products and explosive residues:** use microbial degradation through specialised bacterial products, for example strains of *Pseudomonas* or *Rhodococcus*.
- **For restoring structure, retaining moisture and immobilising toxins:** apply high-quality certified biochar, for example material meeting the EBC-Agro standard, which helps ensure the material itself does not contain hazardous tars or heavy metals. The strongest results are expected from a combined approach using all three methods.

5.3. Evidence from the field

Our trial

- **Location:** Slavutych Farm, Yasna Poliana village, Bashtanka Raion, Mykolaiv Oblast; trial area: 0.5 ha.
- **Biological products description:** a complex of living beneficial soil microorganisms. In our trial, Ecostern Detox + Groundfix were used.
- **Purpose:** used to revitalise soil left biologically 'dead' after hostilities. The bacteria help break down organic contaminants, including fuel, lubricants and chemical residues, and mobilise nutrients by converting unavailable forms of phosphorus and potassium into forms that plant roots can absorb more readily.
- **Biochar description:** wood biochar with an organic carbon content (Corg) of 61.6%. The material meets Class 1 quality requirements under the European Biochar Certificate, EBC version 10.4 (2024), and IBI Biochar Standards v.2.0, providing assurance that the amendment itself does not contain toxic tars or heavy metals.

- **Purpose:** used as a powerful natural filter and sorbent. Its main role is to bind and immobilise heavy metals and dangerous toxins in the soil so that they do not enter the crop. Biochar also loosens compacted soil, retains moisture and provides a protected habitat for microorganisms.
- **Combined application description:** joint application of biochar and bacterial products.
- **Purpose:** to achieve a synergistic, dual effect. Biochar rapidly reduces soil toxicity and creates a protective porous structure. This helps the introduced bacteria survive chemical stress, establish successfully, multiply quickly and realise their full potential in restoring field fertility.

What did the trials show?

Type of damage: physical degradation through compaction and a risk of chemical contamination by heavy metals resulting from hostilities in 2022. Analysis showed that mobile forms of lead and cadmium in the soil were at least 14 times below the maximum permissible concentrations.

Soil: soils of the Southern Steppe of Ukraine, Mykolaiv Oblast.

Restoration methods: use of high-quality wood biochar and biological products, Ecosteron Detox at 1.5 l/ha and Groundfix at 5 l/ha, in three combinations to restore the physical, chemical and biological properties of the soil: Treatment 1 - Ecosteron Detox + Groundfix; Treatment 2 - biochar; Treatment 3 - combined treatment, biological products + biochar.

Duration: 2026.

Table 10. Main results of restoration measures on damaged soils

Indicator	Trial treatment*	Actual value	Difference vs control
Explosive residues	Control	Not detected	Baseline
	Treatment 1	Not detected	No change
	Treatment 2	Not detected	No change
	Treatment 3	Not detected	No change. Residues were already not detected at the start of the trial in April 2026; the assumption that they naturally degraded since 2022 requires confirmation.
Soil bulk density, g/cm³ (lower is better)	Control	1.36	Baseline
	Treatment 1	1.29	Decrease of 0.07 g/cm ³ (improvement)

Indicator	Trial treatment*	Actual value	Difference vs control
	Treatment 2	1.26	Decrease of 0.10 g/cm ³ (improvement)
	Treatment 3	1.23	Decrease of 0.13 g/cm ³ (best reduction in compaction)
Soil moisture, % (higher is better)	Control	11.4	Baseline
	Treatment 1	12.7	Increase of 1.3 percentage points
	Treatment 2	14.6	Increase of 3.2 percentage points
	Treatment 3	15.8	Increase of 4.4 percentage points (best moisture retention)
Mineral nitrogen (N), mg/kg	Control	21.8	Baseline
	Treatment 1	14.3	Decrease of 7.5 mg/kg
	Treatment 2	29.5	Increase of 7.7 mg/kg
	Treatment 3	29.3	Increase of 7.5 mg/kg
Available phosphorus (P₂O₅), mg/kg	Control	57.5	Baseline
	Treatment 1	60.0	Increase of 2.5 mg/kg
	Treatment 2	82.5	Increase of 25.0 mg/kg
	Treatment 3	100.0	1.7-fold increase (+42.5 mg/kg; best nutrient availability)
Available potassium (K₂O), mg/kg	Control	191.2	Baseline
	Treatment 1	170.0	Decrease of 21.2 mg/kg
	Treatment 2	205.0	Increase of 13.8 mg/kg
	Treatment 3	232.5	Increase of 41.3 mg/kg (maximum mobilisation)
Lead (Pb), mg/kg (lower is safer)	Control	0.12	Baseline
	Treatment 1	0.20	Increase to 0.20 mg/kg
	Treatment 2	0.04	Threefold decrease (best immobilisation of the metal)
	Treatment 3	0.20	Increase to 0.20 mg/kg; remains within safe limits

Indicator	Trial treatment*	Actual value	Difference vs control
Zinc (Zn), mg/kg	Control	0.4	Baseline
	Treatment 1	0.3	Decrease of 0.1 mg/kg
	Treatment 2	0.5	Increase of 0.1 mg/kg
	Treatment 3	2.8	Sevenfold increase (active microbiological mobilisation)
Total soil biogenicity, million CFU/g	Control	169.1	Baseline
	Treatment 1	155.1	Decrease of 8.3%
	Treatment 2	168.8	Almost unchanged (-0.2%)
	Treatment 3	146.1	Lower total count in favour of beneficial microflora
Phytopathogens, thousand CFU/g (lower is better)	Control	7.5	Baseline
	Treatment 1	15.0	Twofold increase
	Treatment 2	37.9	Fivefold increase
	Treatment 3	4.1	Decrease of 45.3% (best soil sanitation)

***Types of trial treatment:** Treatment 1 – Ecoston Detoxicant + Groundfix; Treatment 2 – Biochar; Treatment 3 – Complex (biopreparations + biochar); p.p. – percentage points.

For the other micronutrients and metals tested, including iron, manganese and cadmium, values in all treatments remained within safe limits and well below toxic thresholds. Iron and manganese, like zinc, showed nutritionally useful mobilisation into plant-available forms under the combined biochar and biological-products treatment.

Key results

- **Biochar alone was the strongest filter for contaminants.** Used by itself, biochar was the most effective treatment for binding heavy metals, reducing hazardous mobile lead forms threefold and making it particularly useful for chemically contaminated sites.
- **Maximum fertility was achieved only through the combined treatment.** The combination of biochar and biological products produced a strong synergistic effect, delivering the greatest release of plant-available phosphorus, potassium and micronutrients, including a threefold increase in manganese and a sevenfold increase in zinc.
- **Biochar provides an essential 'home' for beneficial bacteria.** Applying biological products without a carbon matrix produced weaker results and did not suppress disease. Only the combined use of microbes and biochar substantially improved soil sanitary condition: dangerous phytopathogens, including *Fusarium*-causing fungi, fell by almost half, supporting the environmental and sanitary safety of future crops.
- **The combined approach was also the most effective for physical soil restoration.** It produced the strongest reduction in compaction, lowering bulk density to 1.23 g/cm³, and the highest moisture accumulation, an increase of 4.4 percentage points, which is particularly important for crop survival in the dry Southern Steppe.

What does the broader academic evidence show?

International scientific research and field trials indicate that one of the most effective and economically attractive ways to 'revive' war-damaged land is to combine biochar with beneficial bacteria.^{28 29}

Biochar acts like a powerful filtering sponge. It absorbs and immobilises heavy metals and toxic substances, helping prevent them from moving through the soil and entering plant roots.³⁰ Living bacteria in specialised products act as natural 'clean-up agents' capable of degrading residues of fuel, lubricants and persistent chemicals.

When the two components are combined, biochar provides a protected habitat for microbes. This improves the chances that bacteria will survive and remain active even under severe

²⁸ Wang, B., Liu, B., Liu, G., Xue, L., Wang, S., & Chen, F. (2026). Synergistic Mechanisms of Biochar and Microorganisms in Soil Remediation: From Heavy Metal Immobilization to Sustainable Agriculture. *International Journal of Environmental Research*, 20(1), 12.

²⁹ Schommer, V. A., Vanin, A. P., Nazari, M. T., Ferrari, V., Dettmer, A., Colla, L. M., & Piccin, J. S. (2023). Biochar-immobilized *Bacillus* spp. for heavy metals bioremediation: A review on immobilization techniques, bioremediation mechanisms and effects on soil. *Science of The Total Environment*, 881, 163385.

³⁰ Maqbool, Z., Shahbaz Farooq, M., Rafiq, A., Uzair, M., Yousuf, M., Ramzan Khan, M., & Huo, S. (2024). Unlocking the potential of biochar in the remediation of soils contaminated with heavy metals for sustainable agriculture. *Functional Plant Biology*, 51(2), FP23257.

conditions, for example in chemically stressed shell craters. If the approach is complemented with phytoremediation crops and beneficial root fungi, the field can recover more quickly and safely.

FARMER STORY

Yurii Bovkun: restoring soil damaged by war



Yurii Bovkun, head of Oksamytt Tavrii Farm in Kherson Oblast, works under some of the most difficult conditions facing Ukrainian agriculture. Part of the farm's land has been affected by hostilities, while the region's dry climate places additional pressure on both soil and crops.

Under these conditions, a conventional crop-production approach is not enough. The farm has to do more than produce a harvest: it must also restore the fertility of land affected by the war.

Oksamytt Tavrii uses No-till together with a package of BTU biological products aimed at soil restoration. This approach minimises mechanical disturbance, conserves moisture and simultaneously addresses the biological condition of the soil.

The farm pays particular attention to Ecosterne Detox. Its use changed the soil's microbiological composition: the share of harmful fungi fell from 21-26% to 4%, while Fusarium remained the only pathogenic fungal group detected.

This is an important result for land affected by hostilities. Restoring the microbiological balance of the soil can reduce disease risks for future crops and create better conditions for plant development.

Biological products are not used in isolation. The farm follows an integrated approach, combining biological products with mineral fertilisers and organic materials and adapting the technology to the condition of each specific site. Results are assessed directly under production conditions: after the combined treatment, the farm recorded higher yields and improved grain quality.

For the coming agronomic seasons, Yurii plans to use biological products together with biochar. This approach is supported by the scientifically demonstrated sorption properties of biochar: it not only creates a favourable habitat for microflora but can also stabilise heavy metals and reduce their toxicity.

The experience of Oksamytt Tavrii shows that even soils damaged by war can gradually be returned to productive use. This is particularly important in Kherson Oblast, where the consequences of hostilities are compounded by high temperatures, moisture shortages and generally difficult farming conditions. Under these circumstances, moisture conservation, minimal mechanical disturbance and restoration of soil biological activity become interconnected parts of a single system rather than separate agronomic measures.

Yurii Bovkun's experience illustrates how combining No-till, biological solutions and organic and mineral nutrition can help restore the fertility of war-damaged land while returning it to productive use.

5.4. Pathways to recovery

Condition / problem	Potential approach	Key requirements	Main limitations
Chemical contamination by heavy metals, especially lead, at explosion sites or where military equipment burned.	Apply biochar alone as a filter and sorbent.	Use only certified biochar, for example material meeting EBC requirements, to avoid introducing new toxins or tars.	High initial cost. On its own, biochar does not restore microflora and may temporarily increase the activity of some soil pathogens.
Complex degradation: severe compaction from machinery, moisture loss, depleted microbiome and locked nutrients.	Combined method: biochar + biological products, including decomposers and nutrient mobilisers + green manure such as white mustard.	Apply the biochar matrix and living bacteria together. Apply biological products in the evening to protect them from ultraviolet radiation.	Highest implementation complexity and initial investment. Requires strict compliance with the combined-application protocol.
Need for sanitary restoration: accumulation of disease-causing organisms and decomposition of organic residues on moderately damaged sites without extreme heavy-metal contamination.	Use biological products only, for example Ecostern Detox + Groundfix.	Sufficient plant-available soil moisture is required for bacteria to survive and multiply actively.	Ineffective for immobilising heavy metals and materially weaker at improving physical soil structure than biochar.

5.5. The economics of restoration

Key result

Assessment and testing cost: approximately UAH 7,000–15,000 per composite sample, depending on the scope of the package, such as basic agrochemistry, heavy metals and toxicology.

Restoration cost: approximately UAH 104,161/ha for materials and machinery operating costs.

Ongoing monitoring cost: depends on the price of the final soil test for residual heavy metals.

Indicative time to restore productive use: 1–2 years; the first year is recommended for green manure crops.

Potential recovery of productivity / income: returning 100% of the damaged area to crop rotation and producing a safe marketable harvest.

Table 11. Cost-benefit analysis (per 1 ha)

Item	No intervention / initial condition	Restoration pathway: biochar + biological products	Difference
Testing	UAH 0	Laboratory soil analysis for heavy metals and toxicants	Additional testing costs
Restoration measures: materials	UAH 0	UAH 102,094: biochar (5 t/ha x UAH 20,000) = UAH 100,000; biological products* (Ecostern 1.5 l + Groundfix 5 l) = UAH 2,094	-UAH 102,094
Machinery / labour	UAH 0	~UAH 2,067: biochar spreading = UAH 423/ha; biochar incorporation = UAH 1,378/ha; spraying biological products = UAH 266/ha	-UAH 2,067
Follow-up testing	UAH 0	Final toxicological soil analysis	Additional cost
Other costs	UAH 0	Sowing green-manure seed, for example white mustard	Seed and sowing costs
Income / productivity	UAH 0: land remains unsuitable or unsafe for food production	Restored productivity, enabling full income from safe marketable crops in subsequent years	Recovery of 100% of future profit from the site
Net result	Loss of the asset: land remains idle and continues to degrade	-UAH 104,161/ha as a first-year capital investment, plus testing costs	Field returned to agricultural use

Note: Biological-product costs use actual prices: Ecostern Detox - UAH 426/l and Groundfix - UAH 291/l. Machinery operating costs are indicative and use the Ukrainian Mini-till rates from Module 2.

Multi-year considerations

Because biochar can remain in soil for hundreds of years, the approximately UAH 100,000/ha expenditure is a one-off capital investment in cleaning and revitalising the damaged site. In subsequent years, the farmer does not need to repeat the biochar application and can instead earn income from safe commercial crops, gradually recovering the initial restoration investment.

Conclusion of the cost-benefit analysis

Restoring damaged soils through the combined method of biochar and biological products requires substantial upfront investment of more than UAH 104,000/ha. However, this is a long-term capital investment rather than a seasonal expense, because biochar does not readily decompose and can continue functioning as a filter and moisture reservoir for decades or centuries. Without restoration, contaminated land remains a stranded asset with zero income. The high initial cost can therefore be economically justified where it allows the field to return to commercial crop rotation and generate income from safe harvests over the long term.

HOW TO RUN A LOW-RISK TRIAL ON YOUR FARM

6.1. Start small, learn fast

Introducing any new technology always involves risk. A practice that has produced excellent results in another region or on an experimental field may perform differently on your land because of differences in soil, microclimate or available machinery.

Switching abruptly to a new practice across the entire farm can create serious financial losses if something goes wrong. A local trial, by contrast, acts as a form of insurance. It allows you to test the technology safely, understand its practical details, build experience on a small area and confirm that it can genuinely be profitable under your conditions without putting the economics of the whole business at risk.

Core principle: test the practice on a limited area, compare it with your usual practice, measure the result and only then decide whether to scale it up.

Nine steps: what to do and when

Follow the steps in this sequence:

- **Before sowing - Steps 1-5:** define the problem, check whether the practice is suitable, design the trial, set success criteria and calculate the expected economics.
- **During the season - Step 6:** carry out the operations and record costs and results.
- **After harvest - Steps 7-9:** compare the results with the control, recalculate the cost-benefit analysis and decide what to do next.

Worked example: biological products on spring barley

This is an illustrative example using data from Module 3. The same approach can be used to complete Steps 1-9 on your own farm.

6.2. Step 1. Pinpoint the challenge

What problem am I trying to solve?

INSERT

Practice I want to test:

INSERT

Why might this practice help?

INSERT

6.3. Step 2. Check the fit

Field, crop	INSERT
Soil conditions	INSERT
Farm conditions	INSERT
Available machinery	INSERT
Available production inputs and resources	INSERT
Technical support required	INSERT

Main risks

INSERT

Readiness decision

To make the decision, answer the following questions:

- Do I have a typical, level field without pronounced problems that can be divided into trial and control plots?
- Do I have the machinery and inputs needed to complete all operations at the correct time?
- Can I afford a possible yield loss on this limited area?
- Can I keep records throughout the season and wait for the results, potentially over several seasons?

If the answer is yes to all questions, you can begin. If you have doubts, resolve them first. If the answer is no, the trial should not be run under current conditions. Select the appropriate option below.

- ☐ Ready to run the trial
- ☐ Some issues need to be resolved first
- ☐ The trial should not be run under current conditions

6.4. Step 3. Design the trial

Planning guide

- Area: 1-10 ha or one typical field, accounting for no more than 5-10% of the total area under the selected crop.
- Duration: one season is usually not enough. For biological products, comparison over several years is preferable; for minimum tillage, 3-4 years is recommended (Module 2); for biochar, monitor the same plots for at least two further years after application (Module 4).

How to position the control

- Place the control plot in the same field, or in a neighbouring field with the same soil type and previous crop.
- Keep the following identical on both plots: crop and variety/hybrid, sowing date and rate, fertilisation system, crop protection and timing of operations.
- Change only one thing: the practice being tested. If both tillage and the product are changed at the same time, you will observe the effect of the whole system rather than the effect of one practice.
- If possible, establish two replications by placing trial and control strips in two different parts of the field.

Trial design

Trial field	<i>INSERT</i>
Trial area	<i>INSERT</i>
Control plot (farm's normal practice)	<i>INSERT</i>
Trial treatment (new practice)	<i>INSERT</i>
Trial duration	<i>INSERT</i>

Baseline conditions

Crop	<i>INSERT</i>
Previous crop	<i>INSERT</i>
Soil condition	<i>INSERT</i>
Moisture availability	<i>INSERT</i>
Fertility	<i>INSERT</i>
Weed pressure or disease incidence	<i>INSERT</i>

Other important conditions	<i>INSERT</i>
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6.5. Step 4. Define success

Agronomic indicators

Indicator 1	<i>INSERT</i>
Indicator 2	<i>INSERT</i>
Indicator 3	<i>INSERT</i>
Indicator 4	<i>INSERT</i>

Operational indicators

Indicator 1	<i>INSERT</i>
Indicator 2	<i>INSERT</i>
Indicator 3	<i>INSERT</i>
Indicator 4	<i>INSERT</i>

Financial indicators

Additional costs/ha	<i>INSERT</i>
Savings/ha	<i>INSERT</i>
Income/ha	<i>INSERT</i>
Net benefit/ha	<i>INSERT</i>

Success criteria

I will consider the trial successful if	INSERT
---	--------

6.6. Step 5. Run the numbers

Before beginning the trial, carry out the relevant cost-benefit analysis using the examples in Sections 2.5 (minimum tillage), 3.5 (biological products), 4.5 (biochar) or 5.6 (soil restoration).

Expected additional costs	INSERT
Expected savings	INSERT
Expected impact on income	INSERT
Expected net benefit	INSERT
Break-even point	INSERT

What needs to happen for the trial to pay off?	INSERT
--	--------

6.7. Step 6. Test and track

Record what you do

Date	Operation	Trial treatment / control	Input / application rate	Machinery	Notes

Date	Operation	Trial treatment / control	Input / application rate	Machinery	Notes

Record costs

Cost item	Trial	Control
Production inputs		
Fuel		
Machinery		
Labour		
Other		

Record results

Adapt the table to your practice: in the Indicator column, enter the measures selected in Step 4, for example field emergence, phytosanitary condition, yield or soil moisture.

Date	Indicator	Control	Trial	Notes

6.8. Step 7. Compare what worked

Indicator	Control	Trial	Difference
Yield			
Income/ha			
Production inputs/ha			
Fuel/ha			
Machinery/ha			
Labour/ha			
Other costs			
Net benefit/ha			

How to distinguish the effect of the practice from random variation

- Collect results in the same way on both plots, from the same area and on the same day.
- If you have replications, compare the averages and check whether the difference points in the same direction in every replication.
- A small difference that changes direction between replications or from season to season is not sufficient for a conclusion. Repeat the trial.

Other results

Soil	INSERT
Crop	INSERT
Operational results	INSERT
Other	INSERT

6.9. Step 8. Revisit the economics

Use the actual values from the Step 7 table and compare them here with the expected values from Step 5.

Indicator	Expected result before the trial	Actual result	Difference
Additional costs/ha			
Savings/ha			
Impact on yield			
Impact on income			
Net benefit/ha			

Why did the actual result differ from what was expected?	INSERT
--	--------

6.10. Step 9. Scale, retest or stop

Rule of thumb: treat a difference as meaningful only if it exceeds the break-even threshold calculated in Step 5 and is repeated across replications or seasons.

Solution	Consider if
Scaling up	• The practice has demonstrated financial effectiveness, with net benefit per hectare clearly exceeding the result on your conventional control plot. • The technology integrated easily and naturally into your production process without causing critical delays to the work schedule. • You did not observe an uncontrolled increase in agronomic risks, such as disease or weeds, and soil condition meets your expectations.
Running another trial	• Weather during the season was extreme or atypical, such as an exceptional drought, prolonged heavy rainfall or hail, and may have materially distorted the results. • Technical or organisational errors occurred when establishing or running the trial, such as late application or incorrect machinery settings. • The economic results were inconclusive, for example cost savings only offset the yield loss and the result was broadly break-even, leaving uncertainty about whether the model is stable.
Suspending or reconsidering the approach	• The trial produced direct financial losses and recalculation shows that the technology does not consistently pay under your specific soil and climatic conditions. • Critical agronomic problems emerged that would require excessively expensive solutions, for example a sharp increase in perennial rhizomatous weeds or a steep yield decline below the break-even threshold. • Full implementation would require major changes to the machinery fleet or staff qualifications for which the farm is not currently ready.