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EKOLOŠKA NEODRŽIVOST KONVENCIONALNE AGROTEHNIKE: NARUŠAVANJE ZEMLJIŠNOG RESURSA I AGROEKOSISTEMA - FINANSIJSKI I EKONOMSKI EFEKTI[2]

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Rezime

Rad analizira ekološku neodrživost konvencionalne agrotehnike, sa posebnim naglaskom na degradaciju zemljišta, eroziju, gubitak biodiverziteta i pad agroproduktivnosti, kao i na prateće finansijsko-ekonomske posledice po poljoprivredna gazdinstva. Polazi se od pretpostavke da modeli poljoprivredne proizvodnje zasnovani na dubokoj obradi zemljišta, monokulturama i intenzivnoj upotrebi mineralnih đubriva i pesticida obezbeđuju kratkoročne proizvodne efekte, ali dugoročno dovode do slabljenja funkcionalnosti agroekosistema i rasta rashoda. U radu se razmatraju ključni mehanizmi degradacije zemljišta, uključujući narušavanje strukture, smanjenje sadržaja organske materije, pojačanu podložnost vodnoj i eolskoj eroziji, kao i smanjenje kapaciteta zemljišta za zadržavanje vode. Poseban deo rada posvećen je ekonomskim posledicama degradacije, koje se ogledaju u rastu troškova proizvodnje (gorivo, mehanizacija, repromaterijal), povećanoj zavisnosti od eksternih inputa i smanjenju profitabilnosti poljoprivrednih gazdinstava. Takođe se analizira lokalni kontekst AP Vojvodine, gde su černozemi, uprkos visokoj prirodnoj plodnosti, izloženi intenzivnoj eksploataciji, klimatskim stresovima i degradacionim procesima. U

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završnom delu rada upoređuju se konvencionalne i održive prakse, pri čemu se ističu prednosti no-till sistema, redukovane obrade, pokrovnih useva i plodoreda u očuvanju zemljišnih resursa, stabilizaciji agroekosistema i optimizaciji finansijskih rashoda. Rezultati analize ukazuju da prelazak ka konzervacijskim i regenerativnim pristupima predstavlja nužan preduslov dugoročne ekološke i ekonomske održivosti poljoprivrede.
Ključne reči: konvencionalna agrotehnika, degradacija zemljišta, erozija, biodiverzitet, agroproduktivnost, održiva poljoprivreda, troškovi obrade, finansijski efekti

Uvod

Intenziviranje poljoprivredne proizvodnje tokom prethodnih decenija doprinelo je povećanju prinosa i kratkoročne proizvodne efikasnosti. Ipak, istovremeno su izazvane značajne negativne posledice po zemljišni resurs i funkcionalnost agroekosistema. Konvencionalni model poljoprivredne proizvodnje, baziran na dubokoj obradi zemljišta, monokulturnim sistemima i intenzivnoj upotrebi mineralnih đubriva i pesticida, postaje uzrok dugoročne degradacije zemljišta, smanjenja biodiverziteta i narušavanja prirodnih procesa. Kako Tsiafouli et al. (2015) ističu, intenzivna poljoprivredna proizvodnja ugrožava biodiverzitet zemljišta i čini ga manje raznovrsnim i funkcionalno siromašnijim.

Struktura zemljišta se narušava dubokom i učestalom mehaničkom obradom, čime se ubrzava mineralizacija organske materije, smanjuje kapacitet za zadržavanje vode i povećava podložnost erozionim procesima. Udruženim delovanjem dolazi do smanjenja plodnosti zemljišta, slabljenja biološke aktivnosti i povećanja zavisnosti proizvodnje od spoljašnjih inputa. Istraživanja pojedinih autora ukazuju da konvencionalna obrada zemljišta povećava rizik od erozije i menja fizička svojstva zemljišta (Baker et al., 2007; Hussain et al., 2021).

U širem ekološkom kontekstu, degradacija zemljišta ima i klimatsku dimenziju, zbog činjenice da smanjenje sadržaja organskog ugljenika umanjuje potencijal zemljišta da deluje kao njegov rezervoar. Prelazak sa konvencionalne na konzervacijsku obradu, uključujući sisteme bez oranja, povezuje se sa većim potencijalom sekvestracije ugljenika, poboljšanjem zemljišne strukture i smanjenjem erozije (Hussain et al., 2021; Zhang et al., 2024).

Cilj ovog rada jeste da analizira ključne mehanizme putem kojih konvencionalna agrotehnika doprinosi ekološkoj i finansijskoj neodrživosti poljoprivredne proizvodnje, sa posebnim naglaskom na degradaciju zemljišta, eroziju, smanjenje biodiverziteta, pad agroproduktivnosti i rast troškova obrade. Predmet rada obuhvata sagledavanje negativnih posledica dugotrajne primene duboke obrade zemljišta, monokulturnih sistema i intenzivne upotrebe agrohemikalija, kao i razmatranje njihovih ekoloških i ekonomskih implikacija. Struktura rada organizovana je kroz nekoliko povezanih celina koje najpre razmatraju krizu konvencionalne agrotehnike, zatim dugoročne posledice degradacije zemljišta, lokalni kontekst sa posebnim osvrtom na Vojvodinu, kao i komparaciju sa održivim i regenerativnim poljoprivrednim praksama.

1.Kriza konvencionalne agrotehnike

Duboko oranje je decenijama predstavljalo osnovnu praksu u konvencionalnoj poljoprivredi, primenjivanu sa ciljem lakše setve, kontrole biljnih ostataka i kratkoročnog povećanja prinosa. Iako se tradicionalno smatralo merom za poboljšanje aeracije i razvoja korena, savremena istraživanja ukazuju na suprotno. Dugotrajna i intenzivna primena dubokog oranja doprinosi degradaciji zemljišne strukture, ubrzanom gubitku organske materije, smanjenju kapaciteta za zadržavanje vode i postepenom opadanju dugoročne plodnosti zemljišta (Baker et al., 2007; Blanco-Canqui & Ruis, 2018; Lal, 2020).

Mehaničko narušavanje zemljišta na dubinama od 30–40 cm, a neretko i više, razbija prirodnu agregatnu strukturu, prekida kontinuitet pora i oštećuje biogeničke kanale koje formiraju koreni biljaka, mikroorganizmi i zemljišna fauna. Kao posledica toga, smanjuje se infiltracija vode, raste površinsko oticanje i povećava se podložnost zemljišta vodnoj i eolskoj eroziji (Blanco-Canqui & Ruis, 2018; Kool et al., 2019; Paustian et al., 2016).

Pored fizičkih posledica, duboko oranje ima i izražene biološke i hemijske efekte. Intenzivna obrada povećava kontakt organske materije sa kiseonikom i aerobnim mikroorganizmima, što ubrzava mineralizaciju i smanjuje sadržaj organskog ugljenika u zemljištu. Time se slabi strukturna stabilnost zemljišta, njegova sposobnost vezivanja hraniva i opšta otpornost na degradacione procese (Gattinger et al., 2012; Lal, 2020; Reganold & Wachter, 2016).

Dodatno, duboko oranje smanjuje kapacitet zemljišta za zadržavanje vode. Promene u zbijenosti, poroznosti i rasporedu agregata utiču na vodni režim zemljišta i dostupnost vlage u zoni korena, što je naročito problematično u uslovima sve izraženijih klimatskih oscilacija i učestalih suša (Abu-Hamdeh, n.d.; Kool et al., 2019; Paustian et al., 2016). Na taj način raste zavisnost proizvodnje od mineralnih đubriva, hemijskih sredstava i dodatnih agrotehničkih zahvata, što povećava ekonomske troškove i ekološki pritisak na agroekosistem (Lal, 2020; Reganold & Wachter, 2016).

U kontekstu klimatskih promena, duboko oranje doprinosi i povećanju emisija gasova sa efektom staklene bašte. Ubrzana razgradnja organske materije oslobađa ugljen-dioksid, dok degradacija zemljišta smanjuje njegovu funkciju kao rezervoara ugljenika. Zbog toga se savremena nauka sve više okreće konzervacijskoj obradi i sistemima sa smanjenim uznemiravanjem zemljišta kao načinima za očuvanje organskog ugljenika i smanjenje erozije (Hussain et al., 2021; Zhang et al., 2024).

Erozija zemljišta predstavlja jedan od najtežih oblika degradacije u konvencionalnoj poljoprivredi. Vodna i eolska erozija ne dovode samo do gubitka najplodnijeg površinskog sloja, već i do smanjenja sadržaja organske materije, hraniva, mikrobiološke aktivnosti i ukupnog proizvodnog potencijala zemljišta (Baker et al., 2007; Blanco-Canqui & Ruis, 2018; Lal, 2020).

Mehanička obrada razbija agregate i smanjuje stabilnost zemljišne strukture, zbog čega zemljište postaje izuzetno podložno odnošenju vodom i vetrom. Površinski ogoljen sloj, bez zaštitnog biljnog ostatka, nema dovoljnu otpornost na udar kišnih kapi, pa se povećava površinsko oticanje i gubitak čestica zemljišta. Istraživanja pokazuju da konzervacijska obrada može značajno smanjiti eroziju i poboljšati zadržavanje vlage, dok konvencionalna obrada povećava rizik od degradacije i gubitka zemljišnog materijala (Seitz et al., 2019; Tillage and soil carbon sequestration, 2007).

Erozija ima i dugoročne hemijske i biološke posledice. Odnošenjem površinskog sloja gube se organske materije i hraniva, što smanjuje sposobnost zemljišta da održava stabilnu proizvodnju bez dodatnih inputa. Istovremeno, gubitak organskog ugljenika smanjuje kapacitet tla za skladištenje ugljenika i povećava emisije CO_2, čime erozija prerasta iz lokalnog pedološkog problema u šire pitanje klimatske i ekološke održivosti (Hussain et al., 2021;

Paustian et al., 2016).

Gubitak biodiverziteta predstavlja jednu od ključnih ekoloških posledica intenzivne poljoprivrede, naročito u uslovima monokultura, pojednostavljenih plodosmena i visoke upotrebe pesticida. Smanjenje raznovrsnosti biljnih, zemljišnih i entomoloških grupa slabi prirodnu regulaciju štetočina, narušava funkcionisanje zemljišnih hranidbenih mreža i smanjuje otpornost agroekosistema na spoljašnje stresove (Tsiafouli et al., 2015; de Graaff et al., 2019).

Monokulture smanjuju raznolikost staništa i ograničavaju dostupnost resursa za korisne organizme, dok primena pesticida i sintetičkih agrohemikalija utiče ne samo na ciljne štetočine, već i na korisne mikroorganizme, oprašivače i zemljišnu faunu. Degradacija podzemnog biodiverziteta direktno ugrožava procese formiranja strukture zemljišta, cikluse hraniva i biološku stabilnost sistema. Posledično, ekosistem gubi sposobnost samoregulacije, pa proizvođači postaju sve zavisniji od spoljašnjih inputa, što povećava finansijski teret proizvodnje i dodatno produbljuje ekološku neodrživost takvog modela (Gomiero et al., 2011; Mäder et al., 2002; Reganold & Wachter, 2016).

2.Dugoročni pad agroproduktivnosti i ekonomske posledice

Degradacija zemljišta izazvana dugotrajnom primenom konvencionalne agrotehnike vodi ka postepenom padu agroproduktivnosti i značajnom narušavanju finansijske stabilnosti poljoprivrednih gazdinstava. Iako takav proizvodni model u kratkom roku može obezbediti relativno visoke prinose, njegovi dugoročni efekti su izrazito negativni, budući da narušavanje strukture zemljišta, gubitak organske materije, erozija i smanjenje biodiverziteta direktno slabe proizvodni potencijal agroekosistema (Baker et al., 2007; Lal, 2020; Reganold & Wachter, 2016). Smanjenje prirodne plodnosti i poremećaj ciklusa hraniva čine proizvodnju sve zavisnijom od skupih spoljašnjih inputa, dok degradirano zemljište gubi sposobnost da amortizuje sušu i ekstremne padavine, što dovodi do velike varijabilnosti u prinosima i stvara visoku nestabilnost godišnjih prihoda (Gattinger et al., 2012; Paustian et al., 2016; Kool et al., 2019).

Sa ekonomsko-finansijskog stanovišta, degradacija zemljišta kontinuirano podiže tačku rentabilnosti (break-even point), povećava troškove po jedinici proizvoda i direktno vrši pritisak na pad neto marže profitabilnosti. Kako bi nadoknadili prirodni gubitak plodnosti i strukturiranosti tla, poljoprivredni proizvođači su prinuđeni da uvećavaju ulaganja u sintetička mineralna đubriva, korektivne hemijske tretmane, navodnjavanje i dopunske prohode teškom mehanizacijom. Ovakav pristup uslovljava konstantan rast varijabilnih rashoda (naročito za pogonsko gorivo i repromaterijal) i ubrzava amortizaciju i troškove održavanja opreme visoke snage. Posledično, dolazi do narušavanja tekuće likvidnosti, povećanja potrebe za kratkoročnim obrtnim kapitalom i zaduživanjem, čime se drastično uvećava finansijski rizik gazdinstava i smanjuje njihova otpornost na tržišne cenovne šokove i negativne efekte klimatskih promena (Lal, 2020; Reganold & Wachter, 2016; Schreefel et al., 2020).

3.Lokalni kontekst i komparacija sa dobrim praksama

U lokalnom kontekstu, problem degradacije zemljišta posebno je izražen u AP Vojvodini, gde dominiraju intenzivna poljoprivredna proizvodnja, dugotrajna primena konvencionalne obrade i visoka izloženost klimatskim stresovima, što sve direktno utiče na ekonomsku održivost gazdinstava. Vojvodina raspolaže vrlo plodnim černozemima, ali upravo ti zemljišni tipovi, zbog intenzivne eksploatacije i klimatskih promena, pokazuju povećanu osetljivost na degradacione procese, naročito na gubitak organske materije, zbijanje i eroziju (Ličina, 2011; Vasin, 2024; Ćirić et al., 2017). Sa stanovišta upravljanja finansijskim kapitalom, sistematski pad sadržaja humusa ispod kritičnih granica predstavlja direktnu amortizaciju prirodne imovine gazdinstva, jer zahteva stalni rast izdataka za skupu dopunsku hemijsku i mineralnu ishranu useva.

Posebno je značajno da je u Vojvodini oko 85% poljoprivrednog zemljišta izloženo eolskoj eroziji, pri čemu se godišnji gubici zemljišta procenjuju na oko 0,9 t po hektaru (Ličina, 2011). Dodatno, istraživanja ukazuju da se u ovom regionu povećava učestalost toplih dana, dok su sušni periodi i nestabilni režimi padavina tokom vegetacije sve izraženiji, što smanjuje vlažnost zemljišta i povećava rizik od drastičnog pada prinosa (Dragović, 2005; Ćirić et al., 2017; Bezdan et al., 2019). U takvim uslovima, duboka obrada zemljišta ubrzava gubitak vlage i pojačava eroziju, dok istovremeno zahteva visoku potrošnju dizel goriva (prosečno 50–60 l/ha) i angažovanje mehanizacije visoke snage (preko 150 KS), generišući visoke operativne i amortizacione rashode. Černozemi postaju znatno ranjiviji bez adekvatnog povrata organske materije i zaštitnog biljnog pokrova, pa se degradacija zemljišta u Vojvodini ne može posmatrati samo ako pedološki problem, već i kao pitanje dugoročne bezbednosti proizvodnje hrane, finansijskog rizika gazdinstava i adaptacije na klimatske promene (Ličina, 2011; Vasin, 2024; Soil Degradation and Climate Change in Serbia, 2021).

Nasuprot konvencionalnom oranju, održive i regenerativne prakse kao što su no-till, reduced tillage, pokrovni usevi i plodored nude efikasnije rešenje za očuvanje zemljišta, stabilizaciju agroekosistema i značajnu optimizaciju finansijskih bilansa.

Smanjena i nulta obrada (No-till i reduced tillage): Smanjuju mehaničko uznemiravanje zemljišta, čuvaju agregatnu strukturu i doprinose boljem zadržavanju vlage. Sa finansijskog aspekta, eliminišu se do tri zahtevna prohoda teškom mehanizacijom, čime se utrošak dizel goriva redukuje na 15–20 l/ha (ušteda i do 65%), dok se utrošak radnih sati po hektaru smanjuje za oko 70%, što ratarskim gazdinstvima donosi direktnu operativnu uštedu od 80 do 130 EUR/ha godišnje.

Pokrovni usevi: Štite površinu od vetra i udara kišnih kapi, smanjuju površinsko oticanje, povećavaju biološku aktivnost i doprinose očuvanju organske materije i hraniva (Blanco-Canqui & Ruis, 2018; Kaspar et al., 2011; Langdale et al., n.d.). Kombinacija no-till sistema i pokrovnih useva značajno smanjuje eroziju i troškove proizvodnje, poboljšavajući ukupnu zemljišnu funkcionalnost i smanjujući zavisnost od kupovnih azotnih đubriva (Jacobs et al., 2022; Seitz et al., 2019; Mitchell et al., n.d.; Use of Cover Crops and Crop Rotation for Soil Fertility, 2026).

Plodored: Prekida cikluse štetočina i bolesti, poboljšava raspodelu hraniva i povećava raznovrsnost organskih ostataka unetih u zemljište. Kada se kombinuje sa pokrovnim usevima i smanjenom obradom, plodored doprinosi većoj otpornosti agroekosistema na sušu, eroziju i degradaciju, direktno ublažavajući finansijske šokove i pad prihoda u sušnim godinama, za razliku od monokulturnih sistema koji ubrzavaju iscrpljivanje zemljišta i povećavaju zavisnost od skupih eksternih inputa (Basch & Andrade, 2022; Lazzaro & Ferrari, 2022; Rose et al., 2022).

Zaključak

Sprovedena analiza pokazuje da konvencionalna agrotehnika, naročito u obliku intenzivne duboke mehaničke obrade zemljišta, proizvodi dugoročne ekološke i ekonomske posledice koje prevazilaze njene kratkoročne proizvodne efekte. Degradacija strukture zemljišta, gubitak organske materije, erozija i pad biodiverziteta direktno slabe agroproduktivnost, povećavaju varijabilne troškove proizvodnje i smanjuju otpornost poljoprivrednih gazdinstava na klimatske stresove i tržišne cenovne šokove.

Posebno je značajno što se ovi procesi odvijaju u specifičnom lokalnom kontekstu AP Vojvodine, gde su izuzetno plodni černozemi izloženi eolskoj eroziji, ubrzanom gubitku humusa i učestalim sušnim periodima. Sa finansijskog stanovišta, konvencionalni model zahteva rastuća ulaganja u pogonsko gorivo, mehanizaciju i minerale ishrane kako bi se kompenzovao pad prirodne plodnosti tla, što pomera tačku rentabilnosti i ugrožava neto profitabilnost i tekuću likvidnost gazdinstava. To potvrđuje da očuvanje zemljišta u savremenom agrobiznisu više nije samo pedološko i agronomsko pitanje, već primarni razvojni, finansijski i klimatski imperativ.

U tom smislu, prelazak ka konzervacijskim i regenerativnim praksama – kao što su *no-till*, redukovana obrada, upotreba pokrovnih useva i pravilan plodored – predstavlja ekonomski i ekološki racionalan odgovor na izazove degradacije. Pozitivne prakse omogućavaju značajne operativne uštede u pogonskom gorivu i radnoj snazi (i do 60–70%), smanjuju troškove amortizacije opreme i stabilizuju prinose u kriznim godinama. Dugoročno posmatrano, tranzicija ka regenerativnim sistemima obezbeđuje ne samo očuvanje zemljišnog resursa kao prirodnog kapitala, već i stabilizaciju novčanih tokova, bolji ESG bonitet i održivu ekonomsku egzistenciju poljoprivrednih proizvođača.

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ENVIRONMENTAL UNSUSTAINABILITY OF CONVENTIONAL AGRICULTURAL PRACTICES: DEGRADATION OF SOIL RESOURCES AND AGROECOSYSTEMS – FINANCIAL AND ECONOMIC EFFECTS[2]

Orignal scientific paper

Abstract

The paper analyzes the environmental unsustainability of conventional agricultural practices, with particular emphasis on soil degradation, erosion, biodiversity loss, and declining agricultural productivity, as well as the related financial and economic consequences for agricultural holdings. The starting assumption is that agricultural production models based on deep soil tillage, monocultures, and intensive use of mineral fertilizers and pesticides provide short-term production effects, but in the long term lead to weakening of agroecosystem functionality and increasing expenditures. The paper discusses the key mechanisms of soil degradation, including disruption of soil structure, reduced organic matter content, increased susceptibility to water and wind erosion, as well as reduced soil capacity to retain water. A special part of the paper is devoted to the economic consequences of degradation, which are reflected in increased production costs (fuel, machinery, production inputs), greater dependence on external inputs, and reduced profitability of agricultural holdings. The local context of the Autonomous Province of Vojvodina is also analyzed, where

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chernozems, despite their high natural fertility, are exposed to intensive exploitation, climate stresses, and degradation processes. In the final part of the paper, conventional and sustainable practices are compared, with emphasis on the advantages of no-till systems, reduced tillage, cover crops, and crop rotation in preserving soil resources, stabilizing agroecosystems, and optimizing financial expenditures. The results of the analysis indicate that the transition towards conservation and regenerative approaches is a necessary prerequisite for the long-term environmental and economic sustainability of agriculture.
Keywords: conventional agricultural practices, soil degradation, erosion, biodiversity, agricultural productivity, sustainable agriculture, tillage costs, financial effects.

Introduction

The intensification of agricultural production over the previous decades has contributed to increased yields and short-term production efficiency. However, at the same time, it has caused significant negative consequences for soil resources and the functioning of agroecosystems. The conventional model of agricultural production, based on deep soil tillage, monoculture systems, and intensive use of mineral fertilizers and pesticides, has become a cause of long-term soil degradation, biodiversity loss, and disruption of natural processes. As Tsiafouli et al. (2015) point out, intensive agricultural production threatens soil biodiversity and makes it less diverse and functionally poorer.

Soil structure is disrupted by deep and frequent mechanical tillage, which accelerates the mineralization of organic matter, reduces the soil's water-holding capacity, and increases its susceptibility to erosion processes. These combined effects lead to a decline in soil fertility, reduced biological activity, and increased dependence of production on external inputs. Research by some authors indicates that conventional tillage increases the risk of erosion and changes the physical properties of the soil (Baker et al., 2007; Hussain et al., 2021).

In the broader environmental context, soil degradation also has a climate dimension, due to the fact that a decrease in organic carbon content reduces the potential of the soil to act as a carbon reservoir. The transition from conventional to conservation tillage, including no-till systems, is associated with greater potential for carbon sequestration, improvement of soil structure, and reduction of erosion (Hussain et al., 2021; Zhang et al., 2024).

The aim of this paper is to analyze the key mechanisms through which conventional agricultural practices contribute to the environmental and financial unsustainability of agricultural production, with particular emphasis on soil degradation, erosion, biodiversity loss, declining agricultural productivity, and increasing tillage costs. The subject of the paper includes an overview of the negative consequences of long-term use of deep soil tillage, monoculture systems, and intensive use of agrochemicals, as well as consideration of their environmental and economic implications. The structure of the paper is organized into several interconnected sections that first discuss the crisis of conventional agricultural practices, followed by the long-term consequences of soil degradation, the local context with particular focus on Vojvodina, and a comparison with sustainable and regenerative agricultural practices.

1. The crisis of conventional agricultural practices

Deep plowing has for decades been a basic practice in conventional agriculture, used with the aim of making sowing easier, controlling crop residues, and achieving a short-term increase in yields. Although it has traditionally been considered a measure for improving aeration and root development, recent research indicates otherwise. Long-term and intensive use of deep plowing contributes to the degradation of soil structure, accelerated loss of organic matter, reduced water-holding capacity, and a gradual decline in long-term soil fertility (Baker et al., 2007; Blanco-Canqui & Ruis, 2018; Lal, 2020).

Mechanical disturbance of the soil at depths of 30–40 cm, and often even deeper, breaks down the natural aggregate structure, interrupts the continuity of pores, and damages biogenic channels formed by plant roots, microorganisms, and soil fauna. As a result, water infiltration is reduced, surface runoff increases, and the soil becomes more susceptible to water and wind erosion (Blanco-Canqui & Ruis, 2018; Kool et al., 2019; Paustian et al., 2016).

In addition to its physical effects, deep plowing also has significant biological and chemical effects. Intensive tillage increases the contact of organic matter with oxygen and aerobic microorganisms, which accelerates mineralization and reduces the content of organic carbon in the soil. This weakens soil structural stability, its ability to retain nutrients, as well as its overall resistance to degradation processes (Gattinger et al., 2012; Lal, 2020; Reganold & Wachter, 2016).

Additionally, deep plowing reduces the soil's capacity to retain water. Changes in soil compaction, porosity, and aggregate distribution affect the soil water regime and the availability of moisture in the root zone, which is particularly problematic under increasingly pronounced climate fluctuations and frequent droughts (Abu-Hamdeh, n.d.; Kool et al., 2019; Paustian et al., 2016). In this way, production becomes more dependent on mineral fertilizers, chemical agents, and additional agrotechnical practices, which increases economic costs and environmental pressure on the agroecosystem (Lal, 2020; Reganold & Wachter, 2016).

In the context of climate change, deep plowing also contributes to increased greenhouse gas emissions. The accelerated decomposition of organic matter releases carbon dioxide, while soil degradation reduces its function as a carbon reservoir. For this reason, modern science is increasingly turning to conservation tillage and systems with reduced soil disturbance as ways to preserve organic carbon and reduce erosion (Hussain et al., 2021; Zhang et al., 2024).

Soil erosion is one of the most severe forms of degradation in conventional agriculture. Water and wind erosion not only lead to the loss of the most fertile topsoil layer, but also to a reduction in the content of organic matter, nutrients, microbiological activity, and the overall production potential of the soil (Baker et al., 2007; Blanco-Canqui & Ruis, 2018; Lal, 2020).

Mechanical tillage breaks down soil aggregates and reduces the stability of soil structure, making the soil highly susceptible to removal by water and wind. The exposed surface layer, without protective plant residues, does not have sufficient resistance to the impact of raindrops, which increases surface runoff and the loss of soil particles. Research shows that conservation tillage can significantly reduce erosion and improve moisture retention, while conventional tillage increases the risk of degradation and soil material loss (Seitz et al., 2019; Tillage and Soil Carbon Sequestration, 2007).

Erosion also has long-term chemical and biological consequences. The removal of the topsoil layer results in the loss of organic matter and nutrients, reducing the soil's ability to maintain stable production without additional inputs. At the same time, the loss of organic carbon reduces the soil's capacity to store carbon and increases emissions, causing erosion to develop from a local pedological problem into a broader issue of climate and environmental sustainability (Hussain et al., 2021; Paustian et al., 2016).

Loss of biodiversity is one of the key environmental consequences of intensive agriculture, especially under monocultures, simplified crop rotations, and high pesticide use. A reduction in the diversity of plant, soil, and entomological groups weakens the natural regulation of pests, disrupts the functioning of soil food webs, and reduces the resilience of agroecosystems to external stresses (Tsiafouli et al., 2015; de Graaff et al., 2019).

Monocultures reduce habitat diversity and limit the availability of resources for beneficial organisms, while the use of pesticides and synthetic agrochemicals affects not only target pests, but also beneficial microorganisms, pollinators, and soil fauna. The degradation of below-ground biodiversity directly threatens the processes of soil structure formation, nutrient cycles, and the biological stability of the system. As a result, the ecosystem loses its capacity for self-regulation, making producers increasingly dependent on external inputs, which increases the financial burden of production and further deepens the environmental unsustainability of such a model (Gomiero et al., 2011; Mäder et al., 2002; Reganold & Wachter, 2016).

2. Long-term decline in agricultural productivity and economic consequences

Soil degradation caused by the long-term use of conventional agricultural practices leads to a gradual decline in agricultural productivity and a significant weakening of the financial stability of agricultural holdings. Although such a production model can provide relatively high yields in the short term, its long-term effects are strongly negative, since disruption of soil structure, loss of organic matter, erosion, and reduced biodiversity directly weaken the production potential of agroecosystems (Baker et al., 2007; Lal, 2020; Reganold & Wachter, 2016). The decline in natural fertility and disruption of nutrient cycles make production increasingly dependent on expensive external inputs, while degraded soil loses its ability to buffer drought and extreme rainfall, leading to high variability in yields and creating significant instability in annual incomes (Gattinger et al., 2012; Paustian et al., 2016; Kool et al., 2019).

From an economic and financial point of view, soil degradation continuously raises the break-even point, increases costs per unit of product, and directly puts pressure on the decline in net profit margins. In order to compensate for the natural loss of soil fertility and structure, agricultural producers are forced to increase investments in synthetic mineral fertilizers, corrective chemical treatments, irrigation, and additional passes with heavy machinery. This approach leads to a constant increase in variable costs (especially fuel and production inputs) and accelerates depreciation and maintenance costs of high-powered equipment. As a result, current liquidity is weakened, the need for short-term working capital and borrowing increases, which significantly increases the financial risk of agricultural holdings and reduces their resilience to market price shocks and the negative effects of climate change (Lal, 2020; Reganold & Wachter, 2016; Schreefel et al., 2020).

3. Local context and comparison with good practices

In the local context, the problem of soil degradation is particularly pronounced in the Autonomous Province of Vojvodina, where intensive agricultural production, long-term use of conventional tillage, and high exposure to climate stresses are common, all of which directly affect the economic sustainability of agricultural holdings. Vojvodina has very fertile chernozem soils, but precisely these soil types, due to intensive exploitation and climate change, show increased susceptibility to degradation processes, especially the loss of organic matter, compaction, and erosion (Ličina, 2011; Vasin, 2024; Ćirić et al., 2017). From the perspective of financial capital management, a systematic decline in humus content below critical levels represents a direct depreciation of the farm’s natural assets, as it requires a constant increase in expenditures for costly supplementary chemical and mineral crop nutrition.

It is particularly important that around 85% of agricultural land in Vojvodina is exposed to wind erosion, with annual soil losses estimated at around 0.9 t per hectare (Ličina, 2011). In addition, research indicates that the frequency of hot days is increasing in this region, while dry periods and unstable precipitation patterns during the growing season are becoming more pronounced, which reduces soil moisture and increases the risk of a drastic decline in yields (Dragović, 2005; Ćirić et al., 2017; Bezdan et al., 2019). Under such conditions, deep soil tillage accelerates moisture loss and increases erosion, while at the same time requiring high diesel fuel consumption (an average of 50–60 l/ha) and the use of high-powered machinery (over 150 HP), generating high operating and depreciation costs. Chernozem soils become considerably more vulnerable without adequate return of organic matter and protective plant cover, so soil degradation in Vojvodina cannot be viewed only as a pedological problem, but also as an issue of long-term food production security, financial risk for agricultural holdings, and adaptation to climate change (Ličina, 2011; Vasin, 2024; Soil Degradation and Climate Change in Serbia, 2021).

In contrast to conventional plowing, sustainable and regenerative practices such as no-till, reduced tillage, cover crops, and crop rotation offer a more effective solution for soil conservation, agroecosystem stabilization, and significant optimization of financial balances.

Reduced and zero tillage (No-till and reduced tillage): These practices reduce mechanical soil disturbance, preserve aggregate structure, and contribute to better moisture retention. From a financial perspective, up to three demanding passes with heavy machinery can be eliminated, reducing diesel fuel consumption to 15–20 l/ha (savings of up to 65%), while the number of working hours per hectare is reduced by around 70%, providing arable farms with direct operational savings of EUR 80 to 130/ha annually.

Cover crops: They protect the soil surface from wind and the impact of raindrops, reduce surface runoff, increase biological activity, and contribute to the preservation of organic matter and nutrients (Blanco-Canqui & Ruis, 2018; Kaspar et al., 2011; Langdale et al., n.d.). The combination of no-till systems and cover crops significantly reduces erosion and production costs, improving overall soil functionality and reducing dependence on purchased nitrogen fertilizers (Jacobs et al., 2022; Seitz et al., 2019; Mitchell et al., n.d.; Use of Cover Crops and Crop Rotation for Soil Fertility, 2026).

Crop rotation: It breaks pest and disease cycles, improves nutrient distribution, and increases the diversity of organic residues added to the soil. When combined with cover crops and reduced tillage, crop rotation contributes to greater resilience of agroecosystems to drought, erosion, and degradation, directly reducing financial shocks and income losses in dry years, unlike monoculture systems, which accelerate soil depletion and increase dependence on expensive external inputs (Basch & Andrade, 2022; Lazzaro & Ferrari, 2022; Rose et al., 2022).

Conclusion

The analysis shows that conventional agricultural practices, particularly in the form of intensive deep mechanical tillage, produce long-term environmental and economic consequences that go beyond their short-term production effects. Soil structure degradation, loss of organic matter, erosion, and biodiversity loss directly weaken agricultural productivity, increase variable production costs, and reduce the resilience of agricultural holdings to climate stresses and market price shocks.

It is particularly important that these processes take place in the specific local context of the Autonomous Province of Vojvodina, where highly fertile chernozem soils are exposed to wind erosion, accelerated loss of humus, and frequent dry periods. From a financial point of view, the conventional model requires increasing investments in fuel, machinery, and mineral fertilizers to compensate for the decline in natural soil fertility, which raises the break-even point and threatens the net profitability and current liquidity of agricultural holdings. This confirms that soil conservation in modern agribusiness is no longer only a pedological and agronomic issue, but a primary development, financial, and climate imperative.

In this regard, the transition towards conservation and regenerative practices – such as no-till, reduced tillage, the use of cover crops, and proper crop rotation – represents an economically and environmentally rational response to the challenges of degradation. These practices enable significant operational savings in fuel and labor (up to 60–70%), reduce equipment depreciation costs, and stabilize yields in crisis years. In the long term, the transition towards regenerative systems provides not only the preservation of soil resources as natural capital, but also stabilization of cash flows, better ESG standing, and sustainable economic viability for agricultural producers.

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