CONSERVATION AGRICULTURE ON UKRAINIAN CHERNOZEMS

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Abstract

As the granary of Europe, Ukraine has seen a significant rise in productivity and efficiency of its agriculture during the past decades. Chernozems are the primary soils in Ukraine. In order to maintain continued increases in grain production, Ukraine needs to implement conservation tillage and other sustainable land management practices to reduce soil degradation. The paper reviews the problem of Chernozems degradation and summarizes the influences of conservation tillage, cropping systems, fertilization, crop residue management, strip-cropping and contour farming on physical, chemical, and biological properties of Ukrainian Chernozems for the past 50 years. The conversion from plow-tillage to minimum tillage and no-till improves infiltration rate, pH and soil organic matter (SOM) in 0- to 10-cm layer and lead to carbon accumulation in fulvic acids and humins. No significant differences in SOM storage were observed among tillage systems in the 0- to 100-cm layer. The five crop rotation increased 0.8, 0.71, 0.94 t ha^{-1} yield of cereals and 5.8, 1.0, 4.2 t ha^{-1} sugar beet under conventional tillage, deep minimum tillage and reduced minimum tillage, respectively. Recommended application of manure in conservation agriculture in the humid zone - 12 t ha^{-1}, in semi-humid zone - 10-12 t ha^{-1} and 8-10 t ha^{-1} in semi-arid zone. Green manure, cover crops and inter crops increased crop yield by 2-10% on Forest-Steppe and Steppe Chernozems. The combination of strip cropping, contour farming, contour bunds, and terracing are particularly recommended for the sloping farmland in order to reduce soil erosion. Land-related policies and relevant legislation in Ukraine are also outlined with an aim to contribute to the creation of guidelines and strategies for further implementation of appropriate practices for sustainable agriculture.

Keywords: Chernozems, conservation agriculture, tillage; cropping systems, fertilization.

Introduction

Worldwide use of soil resources was intensified dramatically ever since the beginning of agricultural civilization and domestication of plants and animals (Dudal, 2002). Land has been cultivated for 2500-3000 years in North and South American continents, 2000-4000 years in Western European and Mediterranean countries, 5000 years in the Middle East (Sandor, 1998), and 4000-6000 years in Ukraine (Lisetskii, 2010). The transformation of natural grassland into crop or pasture land with improper anthropogenic activities such as lack of cover, less input, and overgrazing in particular resulted in an accelerated soil degradation, and is of great concern in every agricultural region of the world (Liu et al., 2010). Ukraine, the granary of Europe, witnessed a significant rise in agricultural? Productivity and efficiency during the first decade of the new millennium due to the intensity of its land use. Ukrainian grain export of wheat, corn and barley was in the eighth, third and first place of the world grain market in 2011 (Potiha, 2011). However, the country has to deal with soil degradation problems in maintaining its grain production momentum. The impact of Ukrainian agricultural production system on the environment contributed to 35-40 % of the total environmental degradation (Sutton et al., 2007). It is estimated that over 8-10 million ha of farmland or 24.6-30.8% of arable lands is degraded and 4.5 million ha of farmland are in the moderate and severely eroded stages. The agricultural lands subjected to water erosion are estimated at approximately 13.3 million ha (including 10.6 million ha of arable lands). Over 1.9 million ha of these soils have been identified as wet or poorly drained. Irrigated land area decreased by 15% over the

past 15 years (Anisimova et al., 2009). More than 500,000 gullies are spread out on 140,000 ha of Ukrainian terrain. The soils with a lost surface horizon of humus accumulation occupy 68,000 ha. Approximately 600,000 ha of arable soils have been covered by eolian medium and coarse textured clastic sediments. Annually, 6 million ha of lands are affected by wind erosion and increased up to 20 million ha in the dust storm periods (Zubets et al., 2010).

Chernozems are the primary soils in the Ukraine, and account for 62% of all agricultural lands and approximately 78% of these soils have been cultivated (Kravchenko et al., 2011). Agricultural management strongly influences soil properties and the assessment of agricultural management on Ukrainian Chernozems may identify the degree these soils are degraded and thus provide priorities for policy-makers and stakeholders in adopting more appropriate practices and guidelines. This review paper summarizes the influences of conservation agriculture on physical, chemical, and biological soil properties on Ukrainian Chernozems. The policies and relevant legislation in Ukraine were also outlined.

Conservation tillage

The moldboard plow inverts the furrow at least 135^{o}, mixes and incorporates the residues and fertilizers within the tilled zone, displaces and shatters the soil aggregates and plant residues. Soil inversion is highly effective in burying crop residues and killing annual and perennial weeds as well as volunteer crops (Kurdyukova and Konoplya, 2011). Other studies have found that tillage systems disturb the weed seeds in different ways (Clements et al., 1996). The conventional tillage buries surface weed seeds in the lower 10-15 cm plow layer, whereas chisel plowing leaves the seeds closer to the surface, and with no-till, 90% of seeds remains in the 0-5 cm top layer. Continual tillage, however, can in some situations lead to soil degradation processes, such as organic matter decline, loss of soil structure and compaction, leaching of calcium and other soil nutrients (Gilley and Doran, 1997). Posing a high risk for crops, conventional tillage (moldboard plow) is seen as a major factor for increased erosion risks (Prager, 2010). The numerous studies (Liu, 2011; FAO, 2002; Gallaher and Maglene, 1987) have shown preferences for conservation tillage for the effects on soil fertility improvement and soil erosion control. The modern concept of conservation tillage defines it as a non-inversion tillage based on: no-tillage, strip tillage, stubble mulching, zonal tillage, reduced or minimum tillage (FAO, 1993), direct drilling, and/or ridge-tillage with retention in all systems of at least 30% of ground cover by residues, and technologies that conserve time, fuel, money, labor, soil structure, nutrients, soil biomass, and soil water (Baker et al., 2007) and reduction in the number of passes over the field (Flower and Rockstrom, 2001). The adoption of minimum tillage under winter crops in the South and South-East regions of Ukraine was successful, and about 50% of arable land area is now under no-till, minimum till, and disking, though conventional tillage practices are prevalent in the humid and semi-humid regions of Ukraine on Spodosols and Alfisols, respectively (Sayko, 2007). Our study, has been conducted on a Typical Chernozem over a 7-yr period from 2006 to 2013 in the Forest-Steppe zone of Ukraine, showed increasing bulk density, compaction, infiltration rate, pH, soil organic carbon (SOC) concentration, carbon of humic acids (HA), carbon of fulvic acids (FA), molecular weight fractions humic acids (HA Mw) with minimization tillage. However, reduced tillage systems had a higher proportion of labile organic carbon , a lower ratio of C in humic acids/C in fulvic acids in comparison with conventional tillage as well as heavier molecular masses of humic acids ranged from 110 to 2000 kDa (Kravchenko et al., 2012).

Cropping systems

The monitoring and control of the crop rotations in Ukraine is, according to the Cabinet of Ministers Directive № 164, exercised by both local authorities and state agencies. Traditionally in Ukraine a crop rotation is made up of eight – ten fields (Tarariko et al., 2012). The crop sequence in a typical forest-steppe rotation is: (1) green manure fallow or grain legume; (2) winter wheat (*Triticum aestivum L.*); (3) sugar beet (*Beta vulgaris L.*); (4) spring barley (*Hordeum vulgare L.*) with perennial grasses; (5) perennial grasses; (6) winter wheat (*Triticum aestivum L.*); (7) sugar beet or corn (*Zea*

mays L.); (8) pea (*Pisum sativum L.*); (9) winter wheat, and (10) sunflower (*Helianthus annuus L.*). Unfortunately, at the current time, the rotation cycle length has been reduced to three or four crops, owing to economic considerations. Crop rotation is very much dependent on region, farm specialization, and available agricultural machinery. Crop rotations are classified into field, fodder, vegetable, and special types. In compliance with Directive № 188/98-BP of Ukrainian Parliament (VVR, 1998), there was adopted a "Contour – ameliorative" system of farming which determined the frequency and diversity of row crops in depending on slope gradient and severity of erosion. The guiding principles of this system were to reduce the number of row-crops (maize, sugar beets, sunflowers) and increase the number of cereals and leguminous grasses in rotations on the slopes. Clean fallows were substituted by green manure fallows. Degraded soils in field crop rotations were replaced by grasslands and forests. The greater parts of plant residues are now left in the fields. The system also introduces strip cropping across the slope, contour farming, shelter belts of forest trees and terraces on plowed land. Tsilyurik (2009) found that crop species impacted soil properties differently. Percentage of water stable aggregates in the size of 0.25-7 mm from the Steppe Chernozems cultivated with alfalfa (*Medicago sativa L.*) was 92.6%, and was decreased to 88.1% in pea, 87.7% in winter wheat, 85.8% in barley, 76.2% in corn, 77.4% in sugar beet, and 74.2% in sunflower. Crop rotation can affect soil properties and increase crop production. A long-term experiment by Gangu et al. (2011) showed that yields of continuous sugar beet were 8.9-10.7 tha^{-1} less than that of the rotation system. The data Demidenko (2012) showed, that a 5-yr crop rotation had an increased yield of cereals on 0.8, 0.71, 0.94 t ha^{-1} and sugar beet on 5.8, 1.0, 4.2 t ha^{-1} than 3-yr crop rotation under conventional tillage, deep minimum tillage and reduced minimum tillage, respectively. Still, 932,000 hectares of arable lands in Ukraine are in monoculture (FAO, 2013). The frequency with which crops are grown affects crop yields.

Fertilization

Though Chernozems are fertile and productive soils, organic and mineral fertilizers are required to maintain their fertility. The increased yield from fertilizers was 50% in Forest Chernozems and 40% in Steppe Chernozems, and additional 20-15% and 40% yield for these soils with irrigation (Nosko, 1991). The commonly used fertilizer rates (kg ha^{-1}) in typical Chernozems are: $N_{80}P_{70}K_{60}$ for winter wheat, $N_{80\text{-}120}P_{90\text{-}120}K_{120}$ + manure 30 t ha^{-1} for corn, $N_{60}P_{60}K_{40}$ for barley, $N_{90\text{-}120}P_{70\text{-}90}K_{40\text{-}60}$ + manure 20-40 t ha^{-1} for rice, $N_{60\text{-}80}P_{60\text{-}80}K_{40\text{-}60}$ for buckwheat, $N_{30\text{-}45}P_{45}K_{45}$ for soybean, $N_{160}P_{170}K_{150}$ + manure 30-50 t ha^{-1} for sugar beet, $N_{60}P_{60}K_{60}$ for sunflower, $N_{45\text{-}90}P_{60}K_{60\text{-}120}$ + manure 30 t ha^{-1} for potato (*Solanum tuberosum*), and $N_{90\text{-}120}P_{40\text{-}60}K_{80\text{-}120}$ + manure 20-30 t ha^{-1} for rape (Marchuk et al., 2011). The way the soils are managed can improve or degrade their natural quality. Applying mineral fertilizers may increase soil acidity (all forms) and enhance the leaching of exchangeable bases. Soil organic matter loss is another of the major characteristics of soil degradations in the Ukraine. Soil organic matter (SOM) content declines steadily during the first 60-year of the virgin Chernozems cultivation of, and maintaines at a relatively stable level afteryears (Degtyarov, 2011). SOC content can be recovered or even increased by applying cattle/pig/poultry manure, compost, peat, sapropel, green manure, plant residues, and cover crops. According the data of Hospodarenko et al. (2012), 45-year cattle manure application of increasing annual rates, noticeably increased percent base saturation, and available nutrient content, improving soil aggregation. Increasing annual average solid manure rate from 9 to 13.5 t ha^{-1} allowed to increase SOM content from 32.4 to 34.3 g kg^{-1}, whereas further increase of manure application annual rate to 18 t ha^{-1} resulted in a less pronounced SOM content increase (to 34.9 g kg^{-1}). Greatest value of total porosity (0.58 m^3 m^{-3}) and infiltration rate (23.85 mm hr^{-1}) was observed by Nazeer and Malik (2011) in the treatment of farm manure (FM) at the rate of 40 t ha^{-1}, followed by FM rate of 20 t ha^{-1} (0.41 m^3 m^{-3}, 15.00 mm hr^{-1}) and without FM (0.36 m^3 m^{-3}, 12.00 mm hr^{-1}). Over the past several decades intensive cropping practices have led to the increasing demand for trace elements to the level higher than the soil can supply. A fundamental difference from traditionally used salt (ionic) form of fertilizers is a nanoform of mineral nutrients. A nanofraction, which is a result of melting and evaporation, followed by

condensation of the vapor phase with an average sizes in the range of 10–150 nm and the corresponding structural phase composition of the solid phase, has signs of a biological functionality and can be used in plant growing. The use of pre-treatment of wheat seeds with colloidal solutions of metals, obtained by electrical discharge treatment, at an application rate of 2 liters per 1 ton of seeds and 2–3 times processing of plants during the growing season enhances winter wheat productivity by 15–20% on Typical Chernozem (Lopatko et al., 2013). The colloidal forms of metals make a positive nutrient effect on the crops grown in calcareous and saline soils. The use of metal colloids normalizes the osmotic properties of cells, since the use of colloidal forms of metal for seed germination under saline conditions, stimulate the swelling and seed germination. Our data (Kravchenko et al., 2015) demonstrate that under the salt stress conditions colloidal forms of manganese, zinc, cuprum, iron, unlike their salts increase the availability of this element for plants, facilitating its admission and participation in biochemical processes.

Mulching, Strip Cropping, Contour farming, Terracing

Cover crops are usually grown together with winter or spring crops in sequence or planted after harvesting. They are grown as autumn/winter annuals and ploughed in to form a green manure prior to sowing the main crop. Total incorporation of 40 t ha^{-1} lupine biomass into soil brings in 180 kg N/ha^{-1}, 40 kg P/ha^{-1}, 68 kg K/ha^{-1}, which is equivalent to 15-30 t ha^{-1} of manure (Makarova et al., 2008). Cover crops not only influence soil properties but also increase crop production. Results obtained by Datsko & Stcherbatenko (2006) demonstrated that the use of cover crops increased yield by 0.17-0.43 t ha^{-1} in winter wheat, 5-9 t ha^{-1} in potato, 5-14 t ha^{-1} in sugar beet, 7-13 t ha^{-1} in silage corn, 0.9-1.3 t ha^{-1} in grain corn, and 0.6-1.0 t ha^{-1} in buckwheat. Eroded Ukrainian Chernozems require the application of mulches at rates depending on soil texture: 1.3 t ha^{-1} for sandy loams, 1.9 t ha^{-1} for sands, and 1.1 t ha^{-1} for silt loams (Zubets, 2010). Tsvey et al. (2009) reported that increasing application rates of cereal straw from no mulch, 2.5 t ha^{-1}, 5 t ha^{-1} and 5 t ha^{-1} + N_{30} resulted in additional sugar beet seed yields of 1.31 t ha^{-1}, 1.41 t ha^{-1}, 1.54 t ha^{-1}, and 1.67 t ha^{-1} respectively. The effect of incorporated mulch depends upon the material used. Univer et al. (2009) found higher strawberry yields were obtained from mulches of white clover *(Trifolium repens L.)*, timothy *(Phleum pratense L.)*, Kentucky bluegrass *(Poa pratensis L.)* and red fescue *(Festuca rubra L.)*. While implementing mulches, it is important to consider the carbon to nitrogen ratio of the organic residues as the organisms consume the soil N and immobilize it if the C:N ratio is above 25. In order to overcome nitrogen deficiency in Ukraine 10-15 kg N/ha^{-1} and 8 kg P/ha^{-1} of chemical fertilizers are applied for each metric t of straw (Grechkosiy, 2008). The effectiveness of mulching in reducing erosion was demonstrated in the field experiments in typical Chernozems (Kravchenko et al., 2010). Minimal tillage with 2.5 t ha^{-1} mulch in the eroded Chernozems saved greater amount of available water for the plants, reduced runoff up to 3.8 m^{-3} ha^{-1}, and increased spring barley grain yield by 1.6 t ha^{-1}. Strip cropping is a method of growing row crops in alternating strips following the contour of the land, in order to minimize erosion (NRCS, NHCP, 2008). Strip cropping is often applied in slopes exceeding 2° steepness or/and 150-200 m length field. Deep heavy-rooted plants in this arrangement should alternate with loosely-rooted plants. The strip widths on 3° slopes are usually about 60-70 m for corn/rape/sunflower, and 70-150 m for spring-winter cereals. The widths of buffer strips made up of grasses and legumes should be no less than 4-6 m on 3° slope and 8-10 m on 3-7° slopes (Tarariko, 2006). Contour farming is not recommended for areas where the slope is less than 1° and the slope is not long (Tarariko and Lobas, 1998). For the field with 1-3° slopes, common practices carried out are: plowing along the lines of the contours, 1-3 m buffer strips comprised of buckwheat, phacelia *(Phacelia)*, oats, annual legumes planted at intervals of 60-80 m; 6-8 m wide forest belts along the field margins and perpendicularly to the wind direction; contour ridges or channels established at 160 m intervals; mulching with cover no less than 65 per cent of the soil surface; establishment of permanent vegetation barriers; growing multiple crops for use in rotations, and application of an additional 10-15% chemical fertilizers. For the fields with 3-7° slopes, recommended practices are: alternative strips across the slope parallel to each other in breadth of

60-80 m under annual grasses mixed with cereals or 20-40 m under corn-legumes mixtures; crop rotations with 40% cereals and 60% legumes; forest belts mixed with bushes 8-10 m wide at an intervals of 200 m; mulching cover no less than 75% of the soil surface; additional 15-20% fertilizers applied. For steeper slopes with very erodible Chernozems, the top priority practices are: growing perennial forage and pasture crops. The benefits of contour farming can be enhanced by combination with the other relevant conservation practices suitable to local soil, relief/geology and climate conditions (Balyuk and Tovazhnyanskiy, 2010). Contour bunds, suitable for slopes 1-7°, are 1.5-2 m wide, 0.25-0.4 m high, spaced at 18-50 m intervals, which were built across the slope to form a water storage area on their upslope side and frequently used in a strip-cropping systems covered by vineyards, gardens, and shrubs. Ivanytska (2010) found the earth bunds increased the effective volume of plum roots to 515 m^3, as compared to 347 m^3 on the slopes without the bunds. Soil total porosity increased to 55%, compared with 49% on the slopes without the bunds, and soil bulk density improved to 1.23 g cm^{-3}, as compared to 1.33 g cm^{-3} on the slopes without bunds. Terracing across the slope intercepts surface runoff and minimizes soil erosion. Three classes of terraces are employed in Ukraine: diversion, retention and bench. The common ground terraces are normally used on slopes less than 7°, with the embankment up to 1 m high and 3-12 m wide (Dzhamal and Shelyakin, 1986). Terracing and slope steepness affect the Chernozems morphological features. Svitlichniy and Chorniy (2007) reported that the soil on the terraced slopes lost less nitrogen, phosphorus, potassium and calcium as compared to non-terraced slopes. Zuza (2011) reports a significant improvement in snow-trapping and available water storage by 12-26 mm with terraces. The same phenomena were earlier reported by Gichka and Timchenko (2007) in spring on terraced slopes.

Policy and legislation in Ukraine

Being a member of Council of Europe since November 1995, and an active participant in the "Environment for Europe" process, Ukraine inherits numerous European obligations and has its own legislation with corresponding measures in soil protection. More than 400 policy measures were developed by EU Member States (Kutter et al., 2011). The soil-relevant policies, addressed to soil degradation, can be outlined in four categories: mandatory measures, voluntary incentive-based measures and awareness-increasing measures and private initiatives (Baumol and Oates, 1979). The European Commission Directive COM (2002) 179 final "Towards a Thematic Strategy for Soil Protection" is one of the most relevant to soil conservation. This Directive describes the multiple functions of soils, identifies the main threats to soils (erosion, decline in soil organic matter and biodiversity, soil contamination, soil sealing, soil compaction, salinization, floods and landslides), and changes in soil characteristics relevant to policy development (EC, 2002). The Sixth Environment Action Program of the European Community entitled "Environment 2010: Our Future, Our Choice" defines the priorities and objectives of European environment policy up to 2012 dealing with a coherent approach to soil protection with legislation, integrating environmental concerns, partnership with business, empowering citizens and changing their behavior, and taking account of the environment in the land-use planning and management (Montanarella, 2005). There are a number of directives regulating soil quality, such as the "Nitrates Directive" 91/676/EEC and the "Water Framework Directive" 2000/60/EC, combined with the "Groundwater Directives" 80/68/EEC and new directive 2006/118/EC. Holistic approach in soil protection and sustainable land use was also targeted in "Soil Framework Directive" COM (2006) 232 and "Global Environment Outlook". The National Ukrainian legislation takes into account interrelationships between soil friendly practices to decrease soil degradation and direct policy measures. The Land Code of Ukraine (effective from January 1, 2002) is the most advanced and closest to European legislative norms. It defines legislative codification and summarizes the rules, regulating land relations into a coherent system, built upon unified principles, taking into account the world experience and requirements regarding harmonization of Ukraine's legislation with legislation of the European Union. Some norms of this act contain direct guidance for land protection, use, reclamation, recovering of contaminated and

damaged soils, restoration of soil fertility, standards in land protection, and state oversight of land use and conservation. The legislative authorities, responsible for budget initiation and regulation in land/soil conservation, are the Ministry of Agrarian Policy and Food, Ministry of Ecology and Natural Resources, The State Agency of Land Resources, State Forest Resources Agency, State Water Resources Agency, and the Statute of the National Environmental Investment Agency of the Ukraine. All environmental principles of land protection are embodied in the Ukrainian Constitution. All agricultural lands in Ukraine, according to the President Decree № 1118/95 and Directive №536, must possess an agrochemical passport. The certificate includes common soil parameters (soil organic matter content and its distribution downwards soil profile, soil texture, storage capacity of available for plants water, acidity, salinity, soil nutrients and microelements content) as well as the concentrations of the soil contaminants determined by the regulations № 4433-87 "Sanitary code of MPC (maximum permissible concentration) of chemical substances in soils". The sanitary condition of the Ukrainian soils is also determined by the State Standard №17.4.2.01-81 "Nature Protection. Soils. Nomenclature of sanitary condition indices". According to the law "On State Control over Use and Protections of Lands", the control of land use and protection is carried out by the authorized body of The State Agency of Land Resources. The control of the observance of laws for soil protection is fulfilled by the authorized body of Ministry of Ecology and Natural Resources, and the monitoring of soil fertility is fulfilled by the authorized body of Ministry of Agrarian Policy and Food. Some older legislative acts contain direct operating instructions for soil management: Directive №320 from 16.05.1967, "Immediate measures of the soil protection against of wind and water erosion", Directive №407 from 02.06.1976, "On land reclamation, conservation and rational use after open-pit mining", but now they are not widely used because of the adoption of new scientific approaches, technology, and standards of soil conservation. The principles of ecological policy in management of land resources are governed by the law "On Environmental Protection". This law enacts norms for environmental state inspection, assessment, standardization and liability of infringement.

Conclusions

According to our findings, the practices of no-till and minimum tillage with the application of 2.5 t ha^{-1} of shredded cereal straw, resulted in 1.31-1.67 t ha^{-1} added yield of sugar beet, surface runoff reduction up to 3.8 m^{-3} ha^{-1}, increases in SOM concentration, infiltration rate, pH, and the amount of available N, P and K. This effect is enhanced by the use of an eight-ten field crop rotation, enriched by small grain crops and leguminous forages. The recommended fertilizers in conservation agriculture include full NPK rates plus manure of 12 t ha^{-1} in the humid zone, 10-12 t ha^{1} manure in semi-humid zone and 8-10 t ha^{-1} manure the in semi-arid zone of the Chernozem region (Marchuk et al., 2011). Green manure, cover crops and inter crops increased yield by 2-10% on Forest-Steppe and Steppe Chernozems. The combination of strip cropping, contour farming, contour bunds, and terracing are particularly recommended for sloping in order to minimize soil erosion, water losses and provide sustainable management practices on sloped farmland. The Ukrainian government is keen to address all recognized soil degradation processes through legislation. However, few policies are relevant to soil conservation or do not address soil degradation, and even if they do, are not oriented towards specific results of improved soil quality with appropriate farm management.

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