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WATER-CONSERVATION AND PROTECTIVE FUNCTIONS OF UKRAINIAN FORESTS IN CATCHMENT AREAS

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Abstract

The objects of the study were the forests in different natural zones in Ukraine. The aim was to reveal the relations between forest cover of water catchments of about 50 rivers of Dnipro, South Bug, Desna, and Siversky Donets basins in different natural zones and the components of water balance, atmospheric precipitations, surface, subsurface and total runoff and evapotranspiration. It was revealed that due to the increase in forest cover up to 20–25 % there was an increase in precipitation up to 95 % in all natural zones of Ukraine. However, further increase in the forest cover did not significantly affect it. The maximum amount of surface runoff (up to 90 %) absorbed by forests was detected when an increase in forest cover was up to 20 % in the steppe part of Ukraine and up to 50 % in Polissya zone. The highest increase in total evaporation – up to 60 % – can be observed if the forest cover increases up to 20–25 % in the Steppe zone and up to 50 % in Polissya and Forest-Steppe zones. Water conservation functions of catchment forest ecosystems are closely related to their spatial distribution and vegetation development as well as the specificities of economic activities within catchments. Significant improvement of Ukrainian rivers is impossible without sustainable management of the territory and increasing its forest cover to certain – optimal or minimum required – level. In this case, a small river catchment is to be the primary territorial unit for land and forest management. Water system sustainability and floodplain agricultural land improvement require complete afforestation of the meandering zones of rivers, as well as meander bars, dead stream branches, coasts of lakes, and scrublands.

Key words: commercial forests, forest cover percent, protective forests, recreational forests, water catchment.

Introduction

Forests are the natural base of the biosphere and play a key role in the conservation of natural resources and in supporting biogeochemical cycles in ecosystems, including climate mitigation targets (Grassi et al. 2017, Ferrara et al. 2016). They form an integral part of the natural environment and are able to improve substantially the environmental conditions, including water balance of the areas where the role of forests takes on particular importance due to the intensive increase of fresh water deficiency. At the same time, too little attention has been given to moisture exchange in landscapes by means of forests as a powerful self-regulating ecosystem (Madrigal-González et al. 2017). In particular, climate and biota are likely seemed to be the primary determinants of carbon fluxes mainly through interacting carbon quantity and quality inputs and through soil water and temperature (Chapin et al. 2012).

Forests on the catchments of rivers and their tributaries are the most powerful factor in stabilizing, at a certain level, the functional organization of natural ecosystems and enhancing their resilience to anthropogenic pressure and climate change (Bonan 2008, Tkach 2012, Kulchytskyi-Zhyhaylo 2018). The forests play important water conservation functions and act as constant natural biological barriers, positively affecting water quality and thus reliably protecting water bodies from silting and pollution (Mikhovych et al.1986, Olijnyk 2014). One of the main goals of Ukraine's forest policy at present is to increase the forest cover to the optimum level in all natural zones. It is one of the strategic areas of activity that can not only increase the timber resources but also stabilize the environmental situation, make a significant contribution to mitigating the climate change and greenhouse effects, restore and preserve biological and landscape diversity, and create favourable conditions for harmonious and sustainable development (Tkach 1999, Olijnyk and Rak 2018).

The results of many years of research show (Mikhovych et al. 1986, Tkach 1999) that the water conservation functions of forests are closely related to their location within catchments. For example, according to Mikhovych et al. (1986), the increase in the forest cover of the catchment areas in Polissya zone to the optimal water-conservation level (23–40 %) will increase the subsurface component of the river runoff by 50–73 mm (the weighted average increase will be 65 mm). It will, on average, exceed the initial value of the subsurface runoff by 500 %. Therefore, under the optimal water-conservation forest cover, the subsurface recharge of rivers and springs will increase by six times compared to that in the treeless catchment areas. The total runoff will increase by an average of 33 mm, or 41 %.

In the Steppe zone, the rise in the forest cover of the catchments up to the optimal water-conservation level will increase the subsurface component of the river runoff by 6–30 mm (by an average of 14 mm), or by 318 %, compared to the initial value of the subsurface runoff in the treeless catchments – i.e. subsurface water recharge of the rivers and springs will increase by 4 times (Mikhovych et al. 1986).

Tkach (1999) has determined the optimal forest cover for the floodplain forests within the Left-Bank Ukraine, which is 60.3 % for Siversky Donets floodplain, 35.4 % for Psel floodplain, and 40.4 % for Vorskla floodplain. The minimum necessary forest cover of treeless lands of the floodplains, however, should reach 15–20 %. These values of optimal forest cover should be taken into account when designing and planting new forests in floodplain areas within river catchments.

Tkach et al. (2008) calculated the optimal water-conservation forest cover, based on the analysis of the structure of catchments of the midstream of Siversky Donets River and its tributaries within Kharkiv Region. The estimated optimal forest cover varied from 18 to 23 % depending on river catchments.

The formation and distribution of forests in river catchments depends on the geomorphological structure, soil conditions, surface relief, and climatic characteristics (Mikhovych et al. 1986; Tkach 1999, 2012; Tkach et al. 2008; Olijnyk 2014). These specificities should be considered in forest management. It is necessary to ensure maximum diversity and differentiation of the catchment landscape, that is, the mosaic of its structural units, to maintain the natural potential. This enables natural resilience, high productivity and aesthetics of the landscape (Tkach 1999).

At the catchment area, the optimal ratio of field, meadow and forest lands is necessary, which provides a stable natural balance and conservation of arable land and its fertility, as well as water resources and other components of the natural complex (Tkach 2012). The ratio of different lands, that is, the landscape balance of the catchment area should match the heat and water balances of a particular region. Field-protective, water-regulating, anti-erosion, roadside, backyard, and other forest belts and tree groups, in addition to their basic protective functions, significantly increase the aerodynamic roughness of the land surface and cause a significant, several hundred meters, rise in airflows, their cooling, and additional precipitation. At the same time, these plantings slow down the surface runoff and change it into subsurface one, especially if combined with other anti-erosion activities (agrotechnical, hydrotechnical, etc.). In this case, forest stands should be placed to fully absorb surface runoff – on watersheds and upper slopes, i. e. in places of its initial formation. Such placement is necessary not only to prevent soil erosion and to improve the water regime of the territory but also to provide effective water protection by the forests. Locating forest shelterbelts in a certain catchment area across the northwestern direction of humid winds is the most rational for water conservation, maximally contributing to the precipitation. The increase in the aerodynamic roughness of the earth's surface and the additional atmospheric precipitation largely depends not only on the area of forest stands per unit area but also on their height. Therefore, preference to tall and, at the same time, few transpiring species should be given when selecting them for planting, taking into account soil and hydrological conditions. Due to the decrease of forest cover below the level required and plowing of large areas, intensive water and wind erosion of the soil begins. Subsequently, much of the arable land loses its fertility and becomes unsuitable for agricultural use, and water bodies become unsuitable even for technical water supply due to siltation and pollution. Therefore, it is necessary to clearly identify which lands in the catchment area should be afforested and not plowed under any conditions (Tkach et al. 1997, Tkach 1999).

Forest stands and farmland form complex forest agrarian coenoses within the catchment area, which are the single paragenetic system. Optimization of agricultural landscapes with forest-reclamation measures is a system of activities aimed at achieving high productivity of the complex while reducing erosion processes, preventing pollution and silting of water bodies, and ensuring the normal hydrological regime of rivers (Tkach 1999). A prerequisite is that the protective plantings in the terrain should form a single biological reclamation system and occupy the area of separate catchments. The role of single plantings is negligible in preventing water pollution.

If it is impossible to increase the forest cover due to the historically formed ratio of different lands, the insufficient forest cover can be compensated by planting protective stands on the treeless banks of the hydrographic network and erosion sensitive open areas.

Another important way to preserve and enhance sustainability and protective properties is to improve forest management.

Tkach (1999, 2012) considered the change in management to the water catchment scale to be carried out in several phases. The first phase establishes standards that allow identifying a minimum catchment area depending on the geographical zone, topography, geomorphological features, etc., as well as the spatial organization and structure of the catchment area. The second stage defines the strategy for optimizing the structure of the catchment, including forest cover, and develops a plan for the transformation of land, taking into account the farm development prospects and the need to gradually achieve an ecological balance of the catchment. In the third stage, management systems should be introduced considering the specificities of the catchment.

The organization of forestry should take into account the location specifics for different purpose forests (both forested areas and shelterbelts). Also, the age structure and species composition of forests should be optimized and appropriate felling should be designed in the catchment area.

The aim of the study was to estimate the impact of forests on water balance components, namely precipitation, surface runoff, total evaporation, and subsurface runoff, as well as its change within Ukraine by natural zones depending on the forest cover of river catchments.

Materials and Methods

Both the materials of our studies and 50-year scientific researches of other authors for about 50 rivers of Dnieper, Southern Bug, Desna, Siversky Donets basins (Fig. 1) in different natural zones of Ukraine were used for analysis and synthesis. The studies were conducted by establishing ecological profiles on the catchments of the investigated rivers (Forest inventory … 2006).

MapInfo Professional 12.5 software and vector map of Ukraine were used to demarcate the boundaries of water catchments. They were determined by divide lines, which passed through the points from which the slopes split off in different directions. Such points are located in the places where the bends in the isohypses are the greatest. Catchment divides follow the ridge lines through the peaks and saddles.

An actual forest cover percent was defined as the ratio of the area covered by forest vegetation to the total area of river catchment (Tkach 2012).

Ecological profiles of the terrain along the slopes were established perpendicular to the terraces of the rivers to study the characteristics of forest formation on river catchments. If the relief allowed, the direction of lines was straightforward. The land navigation was carried out following a compass and map-boards of stands in state forestry enterprises (scale 1:10,000 or 1:25,000).

In selecting the study objects, we analyzed forest inventory data, plantation plans, soil, topographic, geomorphological, geological, landscape, hydrologic, climatic and vegetation maps, and scientific publications regarding this region.

We classified catchments of rivers by part of the area covered with forest vegetation by the method of Grodzynsky (1993) as follows: well-forested – 75–100 %, relatively forested – 50–75 %, medium-forested – 25–50 %, less-forested – 5–25 %, almost treeless – up to 5 %.

The methodology for determining the standard values for optimal water conservation forest cover in the catchment are-

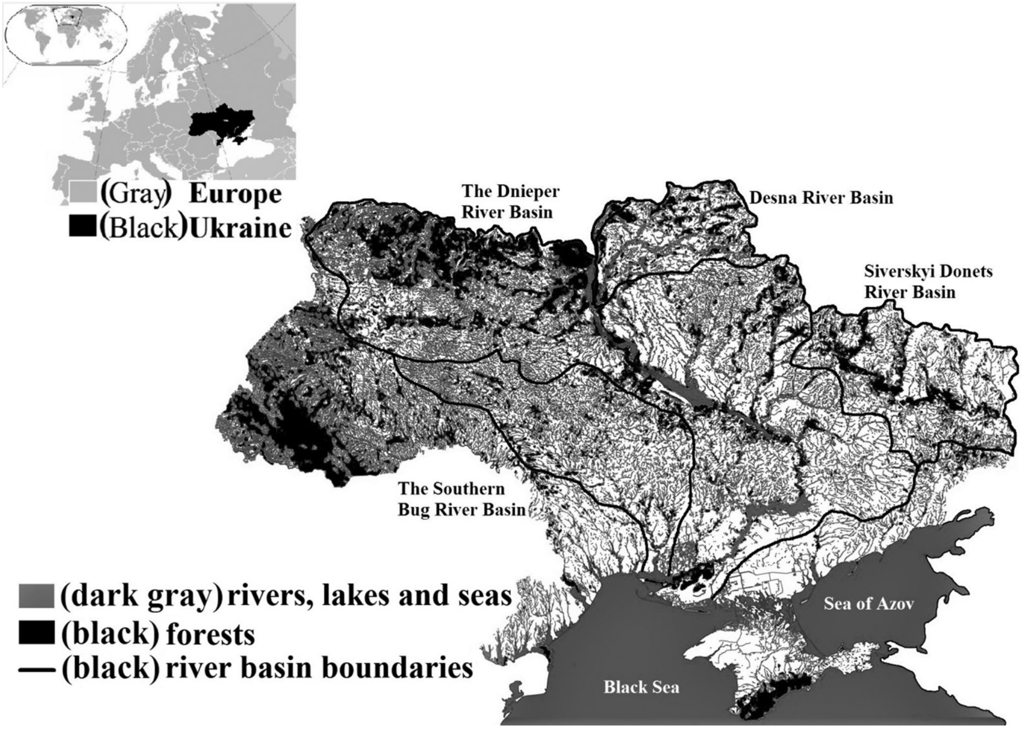

Fig. 1. Location of forests.

as of small and medium-sized rivers, and the quantitative assessment of expected changes in the main components of water balance and river runoff under the optimal water conservation forest cover, with different spacing of forest stands on the catchment area (even and uneven), is based on mathematical modeling of the impact of forest stands on atmospheric precipitation, surface runoff and total evaporation with estimating subsurface runoff change.

The methodology for quantitative estimation of the water-regulating role of a forest is based on a mathematical formula derived from the general formula (1) of the water balance of the land.

$$P = SR + SSR + E, \quad (1)$$

where: P is atmospheric precipitation, SR is a surface runoff, SSR is a subsurface runoff, and E is total evaporation.

Atmospheric precipitation P, surface runoff SR, total evaporation E, and subsurface runoff SSR are the main components of the water balance. The value of SSR remains unknown and could be found by solving the equation with one variable.

The change in subsurface runoff – ΔSSR – is taken as the total indicator of forest water-regulating role. Change in SSR under the influence of forest can also have different effects in different conditions. If ΔSSR value is greater than zero, the forest fulfils a moistening role and, if less than zero, the forest exercises a draining function.

The impact of forest on each component of water balance is obtained by comparing the forested and treeless lands by formula (2) (Mikhovych et al. 1986).

$$\Delta SSR = \Delta P - \Delta SR - \Delta E, \qquad (2)$$

where: ΔP is a change in atmospheric precipitation, ΔSR is a change in surface runoff, ΔE is a change in total evaporation under the influence of forest.

To determine the optimal forest cover for water conservation on the water catchment areas, we used multi-year data on the water balance, rainfall, and index of *SR* in the studied area. For this, observations of gauging stations between 1975 and 2015 were used.

By the method of Mikhovych et al. (1986), mathematical models for changes in the components of water balance and river runoff were calculated for different forest cover percentage, from 1 to 100 %. These calculations showed how the forest stands influenced the river runoff at a full and partial forest cover of the catchment areas and in which specific forest cover the greatest increase in *SSR* can be obtained. The percentage of forest cover, in which there is a maximum increase in *SSR*, is the optimal one for water conservation. Changes in annual runoff under the influence of forest cover were estimated using graphs developed by Mikhovych et al. (1986).

The objects of the study were the forests in Polissya, Forest-Steppe and Steppe natural zones in Ukraine.

Results

The present study shows that forest biocoenoses perform important water-conservation and protective functions. They positively influence on the increase of precipitation amount, total and subsurface runoff and on the whole water balance of landscapes. Due to the *SR* transformation into *SSR*, they substantially improve the quality of water resources, their chemical, physical, bacteriological, thermal properties as well as prevent erosion processes and increase soil fertility. The forests perform also bank-protecting, river-bed-regulating, and anti-meandering functions, reduce the negative impact of floods and mudflows and even positively influence the water balance and climatic parameters on open areas bordered on them.

Summarizing experimental materials obtained during past few decades (Mikhovich 1969; Mikhovych et al. 1986; Tkach 1999, 2012; Tkach et al. 2008; Goroshko et al. 2015) gave an opportunity to get the system of mathematical relationships between the forest cover of water catchments of about 50 rivers of Dnipro, South Bug, Desna, and Siversky Donets basins in different natural zones of Ukraine and the components of water balance, atmospheric precipitations, surface, subsurface and total runoff and evapotranspiration. Change in *SSR* under the influence of forest cover and a specific forest location on a water catchment was taken as the index of water-regulating role of the forests, the value of which determines water content of rivers in a summer low streamflow period when the water deficiency problem is acutest.

It was determined that the rise of precipitation amount (up to 95 %) is observed with the forest cover increasing up to 20–25 % in all natural zones, but its further increase does not substantially influence the precipitation increase. The highest amount (up to 90 %) of the *SR* taken up by the forests is found under forest cover to increase up to 20 % in steppe part of Ukraine and up to 50 %, in Polissya. The largest increment of evapotranspiration (up to 60 %) will be observed at the increase of forest cover up to 20–25 % in Steppe and up to 50 % in Polissya and Forest-Steppe (Table 1).

Table 1. Dependence of change of water balance components, percent from the maximal change value at 100 % forest cover.

Forest cover, %	Precipitation increment change	Surface runoff change		Total evaporation increment change	
		Polissya	Steppe	Polissya, Forest-Steppe	Steppe
81–100	100	98.8–100.0	99.2–100.0	96.6–100.0	96.6–100.0
61–80	99.5–100.0	95.7–98.8	98.1–99.2	86.1–96.6	86.1–96.6
41–60	99.0–99.5	82.9–95.7	95.3–98.1	52.1–86.1	62.1–86.1
21–40	93.0–99.0	53.8–82.9	88.9–95.3	35.3–52.1	52.0–62.1
1–20	3.0–92.0	3.0–51.6	15.0–87.9	1.7–33.4	5.0–50.7

The forests positively influence on all components of water balance. However, this effect is the most evident in the forest *SR*. During it transformation into *SSR*, not only the qualitative characteristics of river runoff (to be recharged by ground waters purged from eroded material and pollutants) will be improved, but also erosion processes will be slow down substantially. This is particularly significant for planning forestry measures for land improving for water catchments with steep slopes.

An optimal water-conservation forest cover will result not only in the maximal increase in the *SSR* but also in improvement of other water balance components: the ratio of *SR* will decrease and the precipitations amount will increase.

The results of the study (Table 2, Fig. 2) indicate that in Polissya, on water catchment of Mena River, for example, *P* influenced by the forest plantations will increase by 47 mm, *SR* will increase by 45 mm, and evapotranspiration will grow by 51 mm, according to territorial norms and for the case of continuous afforestation of the territory. As a result of this, the underground recharge of Mena River will grow due to the increase of *SSR* by 41 mm. However, the maximal increase in underground recharge of the river will be observed not at 100 % of forest cover but at 28 % and the increase of *SSR* will be 51 mm. This is the water-conservation forest cover that will be the optimal one.

Table 2. Changes in water balance under different forest cover of water catchments.

Forest cover, %	Change in precipitation, mm	Change in surface runoff, mm	Change in evapotranspiration, mm	Change in subsurface runoff, mm	Sum of surface runoff and subsurface runoff changes, mm
Polissya, Mena river to the mouth (catchment area 775 km^2, actual forest cover 2 %, *P* 618 mm, *SR* 66 mm, evapotranspiration 508 mm, *SSR* 44 mm)					
100	+47.0	-44.9	+51.0	+40.9	-4.0
60	+46.7	-43.0	+43.9	+45.8	+2.8
28*	+45.8	-30.1	+24.8	+51.1	+21.0
20	+43.2	-23.2	+17.0	+49.3	+26.1
1	+1.4	-1.4	+0.9	+1.9	+0.5
Forest-Steppe, Vorsklytsya river to the mouth (catchment area 1490 km^2, actual forest cover 8 %, *P* 628 mm, *SR* 48 mm, evapotranspiration 568 mm, *SSR* 12 mm)					
100	+38.9	-36.0	+68.0	+6.9	-29.1
60	+38.7	-34.9	+58.5	+15.1	-19.8

Forest cover, %	Change in precipitation, mm	Change in surface run-off, mm	Change in evapotranspi-ration, mm	Change in subsurface runoff, mm	Sum of surface runoff and sub-surface runoff changes, mm
20	+35.8	-25.1	+22.7	+38.2	+13.1
19*	+35.2	-24.6	+21.4	+38.4	+13.8
1	+1.2	-3.2	+1.1	+3.3	+0.1
Steppe, Yevsuh river to the mouth (catchment area – 1190 km^2, actual forest cover – 2 %, *P* 536 mm, *SR* 37 mm, evapotranspiration 429 mm, *SSR* 7 mm)					
100	+17.2	-29.6	+58.9	-12.1	-41.7
60	+17.1	-29.0	+50.7	-4.6	-33.6
20	+15.9	-26.0	+30.0	+11.9	-14.1
17*	+14.9	-25.0	+27.5	+12.4	-12.6
1	+0.5	-4.4	+2.9	+2.0	-2.4

Note: * – Optimal forest cover.

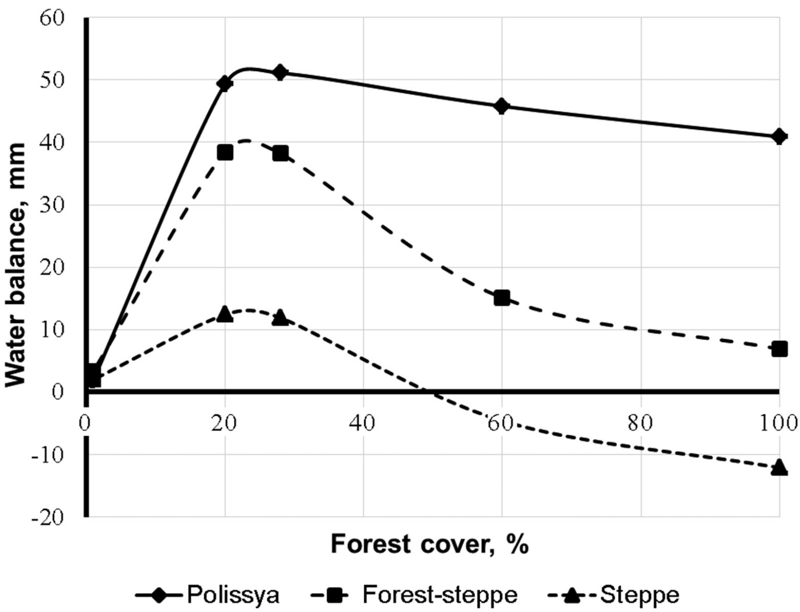

Fig. 2. Impact of forests on change in the water balance (*SSR*) of natural zones.

Toward the south of Ukraine, the changes in water balance characteristics, influenced by the change in forest cover of catchment areas, have certain specific distinctions. At Forest-Steppe (water catchment of Vorsklytsya River), as compared with Polissya, at forest cover of 100 %, an increase in *P* is less and *E* is greater. In such a case, a *SR* is decreased and an increase in the *SSR* is insignificant. At the same time, in the case of the optimal water-conservation forest cover, the increase in the *SSR* will be 38 mm that exceeds considerably the actual water yield accounted for 12 mm.

In the Steppe zone (water catchment

of Yevsuh River), there is even a reduction in the *SSR* at calculated forest cover of 100 %, and in the case of the optimal water-conservation forest cover, its increase will be 12 mm that is almost 2 times exceeds the initial value (7 mm).

On the basis of the calculations performed, the limits of water-conservation forest cover percentage for water catchments of the main Ukrainian rivers were determined (Fig. 3). It is characteristic that the forest cover varies widely within the boundaries of administrative districts of many regions in Dnipro basin, in particular: from 6.7 % to 53.9 % in Volyn Region, from 6.3 % to 65 % in Zhytomyr Region, from 2.4 % to 42.1 % in Kyiv Region.

These results of the research must be taken into account at planning works concerning new forests planting in the administrative districts of the regions. Figure 4 presents the limits of water-conservation forest cover percentage by administrative areas.

Note that, for most regions of Ukraine, the optimal limits of forest cover coincide with the limits of optimal forest cover percentage calculated by Sayko (2008).

The results of the study indicate that the forest cover of Ukrainian regions, including mountain part, should be substantially increased. To get the optimal water-conservation forest cover, at least additional 2.5 million ha of forests need to be created (Tkach 2012).

It is important to take into account the forests placement on water catchments. Results of the fundamental studies testify that the even placing of forest plantations of all kinds along the water catchment area is the most rational in point of water conservation. Performing basic protective functions (field-protecting, water-regulating, erosion-preventive, etc.) they enhance the aerodynamic roughness of earth surface and cause the considera-

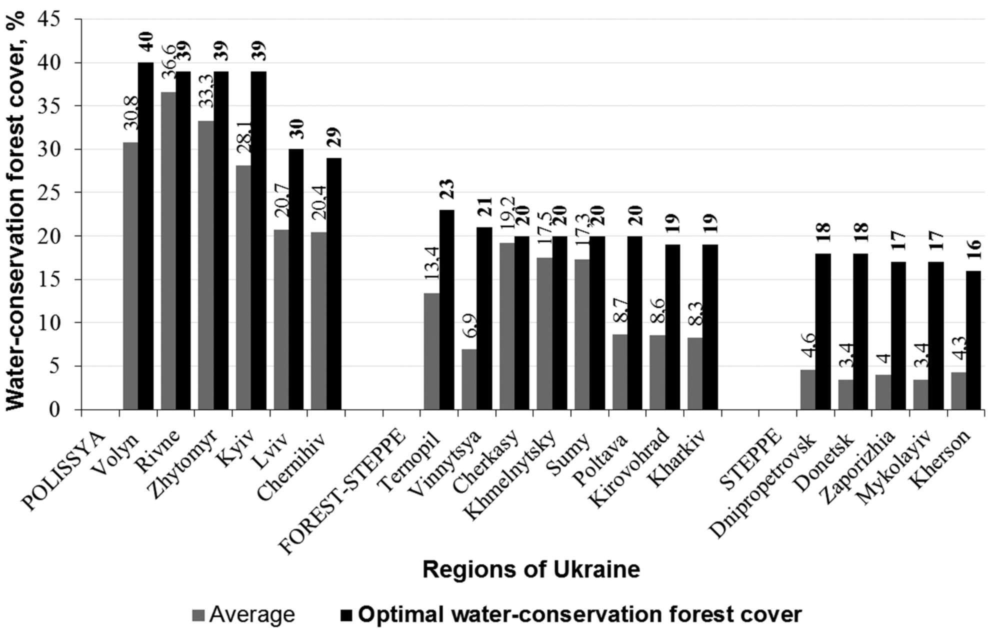

Fig. 3. Average and optimal water-conservation forest cover.

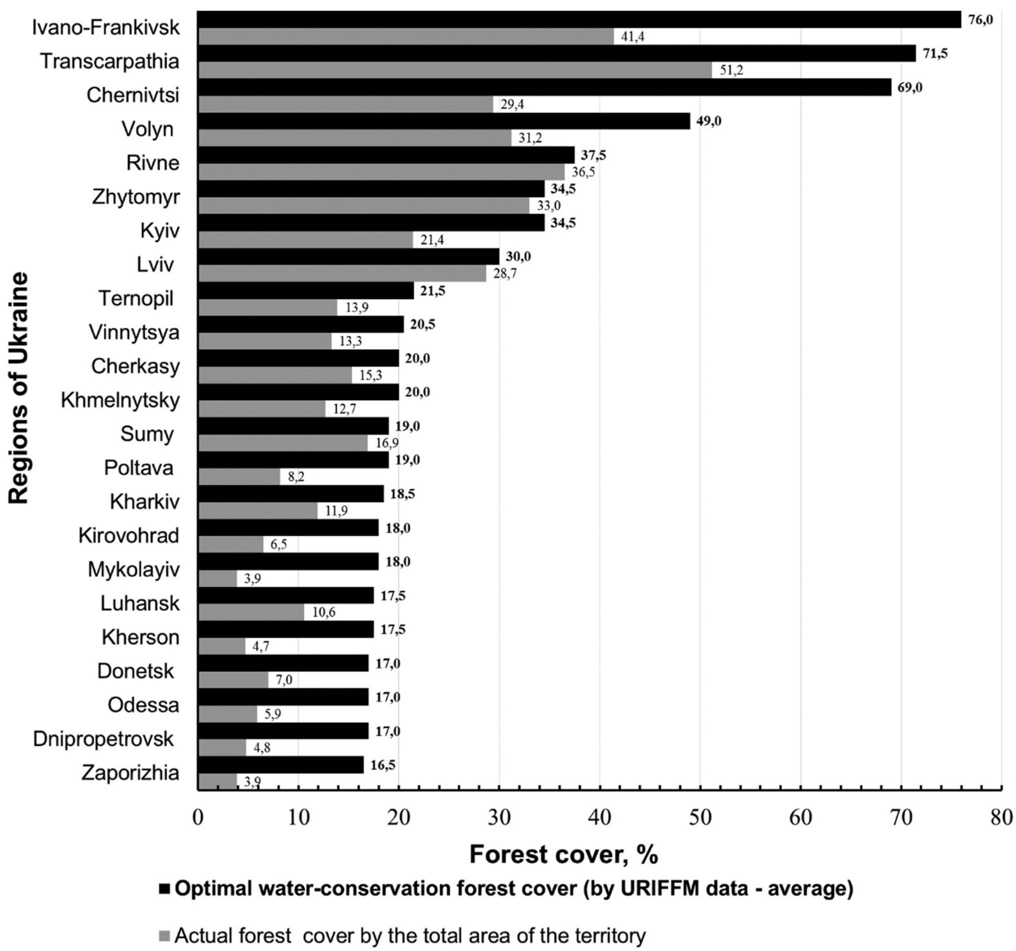

Fig. 4. Actual and optimal water-conservation forest cover percentage.
Note: URIFFM – Ukrainian Research Institute of Forestry and Forest Melioration.

ble (by several hundred meters) raising of air streams, their cooling, and additional precipitation. These plantations, especially when they affect as a whole with other erosion-preventive measures (land treatment, hydroengineering and others like that), entrap *SF* and transform it into *SSR*. Thus, they need to be placed in such a manner as to provide better absorption of the *SR* – on watersheds and heads of slopes – including the places of its initial forming, not only to prevent soil erosion but also to improve the water regime of the territory.

In different parts of water catchments, the water-conservation functions of the forests have certain features. Thus, the riverside forests slow down river meandering processes and destruction of coastlines. The direction and intensity of this influence are determined by the geomorphological features of the valley, the bed-formation water flow rate, the value of forest cover of the floodplain and near river part, and also by species composition of the stands grown in the riverside.

Biological features of the species determine deep root developing that allows holding tightly the upper 2-meter soil layer.

River meandering zone, meander development coefficient, and turning angle are decreased with the increase of forest cover of the floodplain (Table 3).

Table 3. Dependence of morphometric indexes of river-beds on the pattern of riverside afforestation.

Pattern of riverside afforestation	Meander development coefficient	Meandering zone, m	Turning angle, degree
Vorskla River			
Non-afforested	1.44 ±0.05	508 ±38	144 ±7
Afforested from one side of the river-bed	1.13 ±0.03	338 ±40	113 ±14
Afforested from the both sides of the river-bed	1.13 ±0.04	324 ±62	109 ±13
Psel River			
Non-afforested	1.87 ±0.11	804 ±61	152 ±5
Afforested from one side of the river-bed	1.45 ±0.09	613 ±77	149 ±6
Afforested from the both sides of the river-bed	1.39 ±0.06	588 ±48	132 ±7
Siversky Donets River			
Non-afforested	1.71 ±0.27	613 ±107	156 ±14
Afforested from one side of the river-bed	1.60 ±0.21	515 ±70	146 ±11
Afforested from the both sides of the river-bed	1.46 ±0.17	446 ±40	137 ±10

In floodplains of the largest rivers of left-bank part of Ukraine, anti-meandering and river-bed-stabilizing functions are peculiar not only to forest stands directly contacted with a river-bed but also to those growing on the distant floodplain sites. The forest stands significantly slow down the bank eroding velocity on adjacent woodless areas of the rivers. Thus, if in the case of continuous afforestation of the floodplain site near a river but only partial afforestation of all floodplain the calculated meandering zone of Siversky Donets is 446 m, then assuming continuous afforestation of all floodplain the meandering zone will be increased up to 229 m. Herein, a new type of out-of-boundary influence of a forest appears.

Discussion

As the result of the study shows, the forests of the left-bank part of a floodplain influence more significantly on the meander morphometric parameters and meandering processes as compared with the forests of the right-bank floodplain. This aspect should be taken into account when establishing forest shelterbelts in floodplains.

Economic activity in floodplains should be aimed at the maximal afforestation of meandering zone. The average width of this zone will determine the width of bank-protecting forest strips, which belong to the number of especially valuable areas of the forest resource. In particular, the width of such strips must be 150 m for Vorskla River, 200 m for Siversky Donets River, and 250 m for Psel River (Tkach 1999).

Agricultural part of floodplains should consist exceptionally of meadows, haylands, and pastures. Water system sustainability and floodplain land improvement require complete afforestation of the meandering zones of the rivers, as well as meander bars, dead stream branches, coasts of lakes, and scrubland as agricultural part of floodplains.

A maximal effect is possible to be achieved by the creation of forest hydroengineering complexes. Proof of that is the high efficiency of functioning of Kaniv, Norynsk and Rzhyshchev forest hydroengineering reclamative systems. Thus, only at Kaniv system, 1,820 ravines were stabilized. As a result of it, about 22 thousand ha of fertile croplands have been prevented from disturbance, 10 thousand ha have been restored for agricultural use, and the additional amount of wood has been got, the annual increment of which on the afforested areas is about 40,000 m^3.

However, the current state of hydroengineering constructions deteriorates steadily; their considerable part became out of action. It reduces the efficiency of reclamative influence of the protective forest planting substantially. The state of many water-regulating plantations is also unsatisfactory. At a rough estimate, the forest stands perform reclamative functions effectively only on the one-third of the area, and about 40 % of water-regulating forest strips need a complete or partial reconstruction. On large areas, forest strips had been created without considering scientifically reasonable standards and requirements.

A complete use of forest reclamative functions is possible only if the related systems of protective forest plantations and strips having the certain purposes are created in accordance with natural zones and types of Ukrainian landscapes. It is clearly defined on the well-known objects of Dokuchaev's expedition, Starobilsk and Velykoanadolsk areas, where scientists from Mariupol and Luhansk Forest Melioration Research Stations of URIFFM carry out investigations during many decades. The results are unrivaled throughout the world agroforestry science. They testify that the system-based placing of forested areas and forest strips in hard steppe conditions brings a vast improvement of the microclimate: the air humidity rises, the range of extreme values of air and soil temperatures is reduced. During vegetation period, nonproductive moisture evaporation is decreased by 20–30 % and transpiration ratio, by 30–35 %. In the systems of strips, the amount of the trapped snow rise by 30–50 %, the conditions of winter crops overwintering is improved, the soil is supplied additionally by 10–20 % of water and waterborne soil movement is decreased by 1.5–2 times.

In the forest strips systems, the spring water tables rise more moderately, and the summer lowering of the soil water table is slow down. That, therefore, creates the best conditions for water vapor condensation on the soil, thereby dew is falling in a greater amount and remain for a longer period here, and moisture enriched air removing is decreased noteworthily. Moreover, it is currently thought that water balance and temperature might be one of the most important factors for determining soil carbon fluxes and storage (Chapin et al. 2012).

Lately, the discussions continue on the practicability of the creation of new forests in Steppe, as an increase of forest cover percentage in this natural zone, apparently, will result in loss of faunal and floristic diversity and will have a detrimental effect on Red List species. Related to this issue, it is worth noticing that in past centuries the forest cover percent of Steppe was several times higher. However, the forests grew here not everywhere, but only on certain areas: mainly in river valleys, effectively protecting them from a silting-up, and also in ravines and lower reaches. Considering extremely large plough-disturbance of the lands, the steady decrease of soil fertility, many small rivers ending and effective reclamative influence of the forests, it is necessary to study and clarify the regional standards of forest cover percentage and determine the structure of the forests and protective forest strips. Only those lands should be afforested that are suitable for the regeneration and are not in the list of such objects as valuable faunal and floristic complexes that are the subject or can be the subject of protection.

For planting new forests in Steppe, it is necessary to follow landscape-ecological principles on that new strategy of afforestation on sands of Lower Dnipro valleys was developed. It provides the following:

• Forest cover should not exceed 75 % of the area on hilly sands (50 % on burnt areas) and 50 % on flatly and hummock lands (40 % on burnt areas);

• Afforestation of lowlands of 0.5 ha between hills as well as tops of hills and sandy terraces is not advisable;

• Hills of up to 5 m height and their slopes must be afforested. Such areas should be classified as 'Reclamation areas';

• It is necessary to protect the areas with natural regeneration of forest species and to implement measures on natural regeneration assistance.

The optimal forest cover comprises not only the optimal area of the forests but also their optimal structure that is a balance of the massive and linear plantations of the certain functional uses that will provide an equilibrium between the productivity of landscapes and quality parameters of the environment (Tkach et al. 2008, Goroshko et al. 2015).

Depending on the ecological and socio-economic role of the forests it is reasonable to distinguish the systems of the massive plantations (merchantable, protective, recreational forests, and plantations of environmental, scientific, historical and cultural purposes) and systems of the linear plantations (field-protective, ravine, growing along watercourses, etc.) (Bondar et al. 2016).

During the creation of new forests and protective forest strips of different designated use, which have an optimal structure, it is important not to disturb the natural meadow and bog coenoses and the natural integrity of all of the components of ecosystems: animal and plant kingdom and microorganisms (Tkach et al. 2016).

Therefore, further research is necessary to study the typification of territory of Ukraine by the qualitative characteristics of ecological disturbances of cultivated lands and to develop, selectively to the types of landscapes, the zonal systems of forest improvement measures, as well as the technologies of the creation of special-purpose forests for the effective land protection against water erosion and soil retirement, of the water resources improvement, desertification prevention and biodiversity conservation.

The conducted studies allow us to formulate problems to be solved in agricultural afforestation as follows.

Scientific:

• To ground the optimized systems of protective forest plantations of different uses selectively to the types of landscapes, taking into account the developed limits of protective forest cover;

• To improve the ecological and economic evaluation of reclamative functions of the special purpose protective forest stands.

Legislative and regulatory:

• To develop the way to change the economic management principles to catchment-landscape ones;

• To practice a mechanism of a simplified land cession for the creation of protective plantations and to legitimate it.

Organizational:

• To inventory the areas covered by protective forest strips and other plantations on reserve land;

• To develop land management plans in economies, which should include planning of forest strips of the certain functional uses;

• To transfer, at no additional charge, the protective forest strips and protective forest plantations into ownership or for the use (by lease or on a permanent basis) to natural and legal persons and to conduct forest management there;

• To draft proposals on making corresponding changes and additions regarding the legal status of the protective forest strips and plantations;

• To resume the activity of State Service of Agroforestry.

A water catchment should be an elementary territory economic unit during planning and implementation of economic measures. Within the boundaries of certain water catchment, one should determine the balance and the areas of massive and linear plantations. These are forest cover optimization principles on which forest management strategy and forest reclamation should be based in Ukraine.

The solution of the problem will be also facilitated by the implementation of measures documented in 'Concept of agroforestry in Ukraine', authorized by Cabinet of Ministers of Ukraine (in 2013).

It is necessary also to provide the implementation of top-priority business measures for maintenance of protective forest strips and forests on reserve land. Primarily, an inventory should be made for such plantations, and then land management plans should be developed concerning the allocation of the areas on the reserve lands under the forests and protective strips for the further assignment for charge-free ownership, use by lease or sustained use. Furthermore, according to Forest Code, it is reasonable to transfer the closed land plots covered with forest vegetation, of more than 5 ha in area, being a part of lands of farms and other economies, into natural or legal people's charge-free ownership. Land plots covered with forest vegetation, including forest strips, of more than 5 ha in area, being a part of lands of farms and other economies, should be transferred for natural or legal people's use by lease with a minimum land charge. Woodlands bordering forest areas should be transferred for the sustained use of forestry enterprises, establishing in such a case the corresponding land servitude for joint owners and land users for unimpeded access to protective forest strips and plantations (for the proper protection and forest tending). After that, an inventory should be made for these plantations. For the maintenance and creation of new protective forest strips and forests, it is expedient to resume the activity of State Service of Agroforestry and also to make corresponding changes and additions in laws and regulations in relation to the legal status of such plantations.

In the past, the protective planting projects were the component part of inner land-utilization system of former collective and state farms; the targeted financing of protective strips creation had been provided, including publicity-funding. A similar approach would be applied even today when developing plans for land management, inventory, and territorial planning projects of different levels. Projecting for the creation of new forest plantations should be also carried out during national ecological network forming.

The history of successful farming in many developed economies of the world indicates the importance of the use of forest land-reclamations as an integral component of modern soil management. In these countries, the protective planting creation programs are adopted at a state level and budgeted; such measures encourage owners to implement the programs on their territories.

The successful solution of the stated problems will improve not only the water regime of landscapes but also the efficiency of agribusiness.

The presented results are of prime importance as they determine strategic sector of optimization of forest cover in Ukraine. Creation of the new forests, in Steppe and Forest-Steppe as a priority, will substantially improve the hydrological regime of the landscapes.

Conclusions

Forests have a positive effect on all components of water balance, especially on the surface runoff. By changing surface runoff into subsurface one, not only the quality indicators of river runoff will be improved, but also erosion processes will be slowed down. It must be given due attention when designing forest reclamation works for water catchment areas with steep slopes.

It was revealed that due to the increase in forest cover up to 20–25 % there was an increase in precipitation up to 95 % in all natural zones of Ukraine. However, further increase in the forest cover did not significantly affect the increase in precipitation. The maximum amount of surface runoff (up to 90 %) absorbed by forests was seen when an increase in forest cover was up to 20 % in the steppe part of Ukraine and up to 50 % in Polissya zone. The highest increase in total evaporation – up to 60 % – can be observed if the forest cover increases up to 20–25 % in the Steppe zone and up to 50 % in Polissya and Forest-Steppe zones of Ukraine. The estimations can be used to determine the limits for water-conservation forest cover within the catchments of the main Ukrainian rivers.

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