Impact of Climate Change on Energy Relations in Agroecosystems

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Abstract: The paper considers formation mechanisms of material and energy flows as well as trophic relations in agroecosystems in response to climate change. Based on the research of separate crop rotations in typical farms, the authors found the regularity of commodity crops timing to field crop rotations (on sections of watersheds), and fodder - to slopes as part of special crop rotations. In the course of the research, the authors developed a method assessing the rational use of natural resources of the territory for fodder production, created maps "Correlation between energy flows of producers and consumers", "Formation of energy flows in agro-ecosystems" and "Deformation of energy relations in agro-ecosystems". The results prove that formation of artificially supported agrophyto- and zoocenoses directly affects the spatial structure of agro-landscapes. The article explores general strategy of rational agrolandscapes' formation in the conditions of climate change, substantiating the list of forage plants adapted to arid climates.

1 INTRODUCTION

Given that agriculture is the closest in terms of type of material and energy relations to natural ecosystems, the search for such forms of its management (specialization) that would meet the natural capabilities of a given area is probably the main task to promote sustainable nature in agriculture. And in recent years, the task is complicated by destructive processes in the geosphere of our planet, which are caused by global climate change.This is best solved by an adaptive approach, or a system of agricultural production, which ensures maximum payback of biological products of each unit of anthropogenic energy introduced into the agro-ecosystem. Violation of the adaptive approach leads to a significant increase in the cost of agricultural products or in general to a "zero effect" when introduced to new areas plants or animals do not take root (examples: attempts to grow corn far north of its distribution area, growing tea bush in Transcarpathia, in the southern steppe of Ukraine).

History of agricultural development shows that with the "compaction" of geographical space (due to population growth), natural forage lands for cattle fattening has become in short supply. That is why at the turn of 19-20 centuries, the concept of "fodder arable land" appeared in the structure of arable land. (Sonko et al., 2019). In fact, the fodder arable land did not exceed 15-20% at the beginning of industrialization. Such values of this indicator, in our opinion, determine the conditional limit from which

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drastic anthropogenic transformation of natural landscapes begins, reformatting energy relations in agroecosystems. After all, according to the research of well-known scientists, the consumers of the biosphere (including domesticated) ones, should receive no more than 1% of the total volume of energy flow coming from the Sun to the planet's surface to ensure biosphere sustainability.

Today, this figure is 10% (Arskiy et al., 1997). The border between the steppe and the forest-steppe has already shifted by 50-100 km to the north. This will inevitably lead to the replacement of traditional crops in the main grain wedge with drought-resistant ones, and, consequently, a change in agricultural specialization (Sonko et al., 2019).

A number of works have analyzed the "reaction" of agriculture to climate change (Kovalova, 2001), (Baliuk et al., 2021), (Basok and Bazieiev, 2020), (Zakharova, 2019), (Melnichenko and Petrovskyi, 2020), (Bredikhina, 2020), (The World Bank, 2021), (Duval et al., 2021), (Martin-Collado et al., 2019), (Ukraine, Cabinet of Ministers of Ukraine, 2021). They are mainly about soil resources and adaptation of crop production to such changes. This is logical, because producers in the biosphere account for more than 98% of its total biomass, and plants are the first to "react" to climate change. As for consumers, the impact on them is "hidden" in complex trophic relationships in populations of predators, herbivores, and others. In agroecosystems, such relations are the least tangible due to human regulation of material and energy flows formed in them. Actually, this article considers the formation mechanisms of such flows as well as trophic relations in agroecosystems.

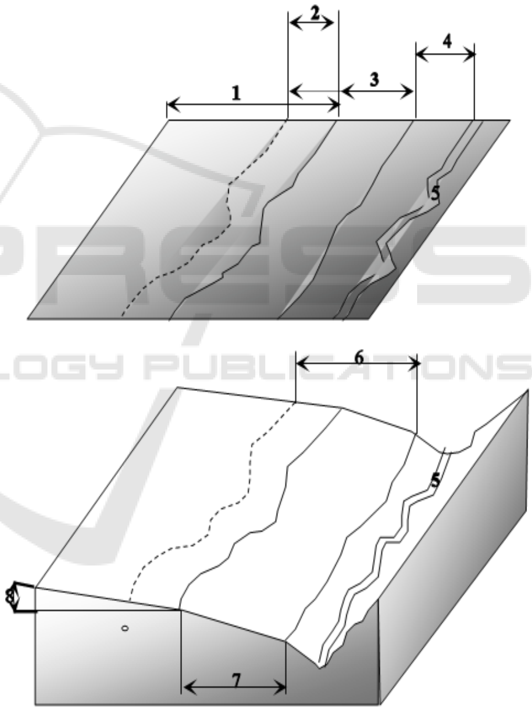
Due to climate change, overpopulation of livestock has another negative impact, which is constant emissions of greenhouse gases (mainly methane). According to some current estimates, it is methane (rather than carbon dioxide) that poses a much greater risk in terms of global warming. (Korsak et al., 2021).

However, we consider the ratio of land use types in agro-landscapes not only as a purely statistical category, but, above all, as an indicator, characterizing energy relations in agroecosystems. In particular, in agricultural ecology, a kind of common denominator for the quantitative comparison of crop and livestock can be the amount of energy received by producers (plants) and consumed by consumers (a special case - herbivores) (Pakhomova, 2014). Energy features are the basis for allocation of food chains at different trophic levels in ecosystems. Thus, commodity crop production is characterized by food chains such as "soil-plant-human". Here, the energy accumulated by plants comes directly to man as a consumer of the highest quality.

Another trophic level inherent in agroecosystems connects one more consumer "herbivore" animal " to the chain after the "plant" - where the energy accumulated by the producer is deposited in the form of" milkings "and" gains ".

Such trophic relations are in agrolandscapes in certain ecological functions of their individual areas, providing food for different types of organisms. In particular, it is more correct to classify the areas sown with fodder crops or those that are actually used as fodder, as "the habitat area of primary consumers", or rather their ecotope.

The authors have studied trophic relationships in agroecosystems designed for agrolandscapes before (Sonko et al., 2019). Fig.1. shows the results of these studies.



Symbols: 1 - commercial arable land; 2 - area "returned" in the form of concentrated feed; 3 - forage arable land; 4 - natural forage lands; 5 - the river; 6 - statistical forage area; 7 - potential forage area; 8 - inclination angle less than 5º.

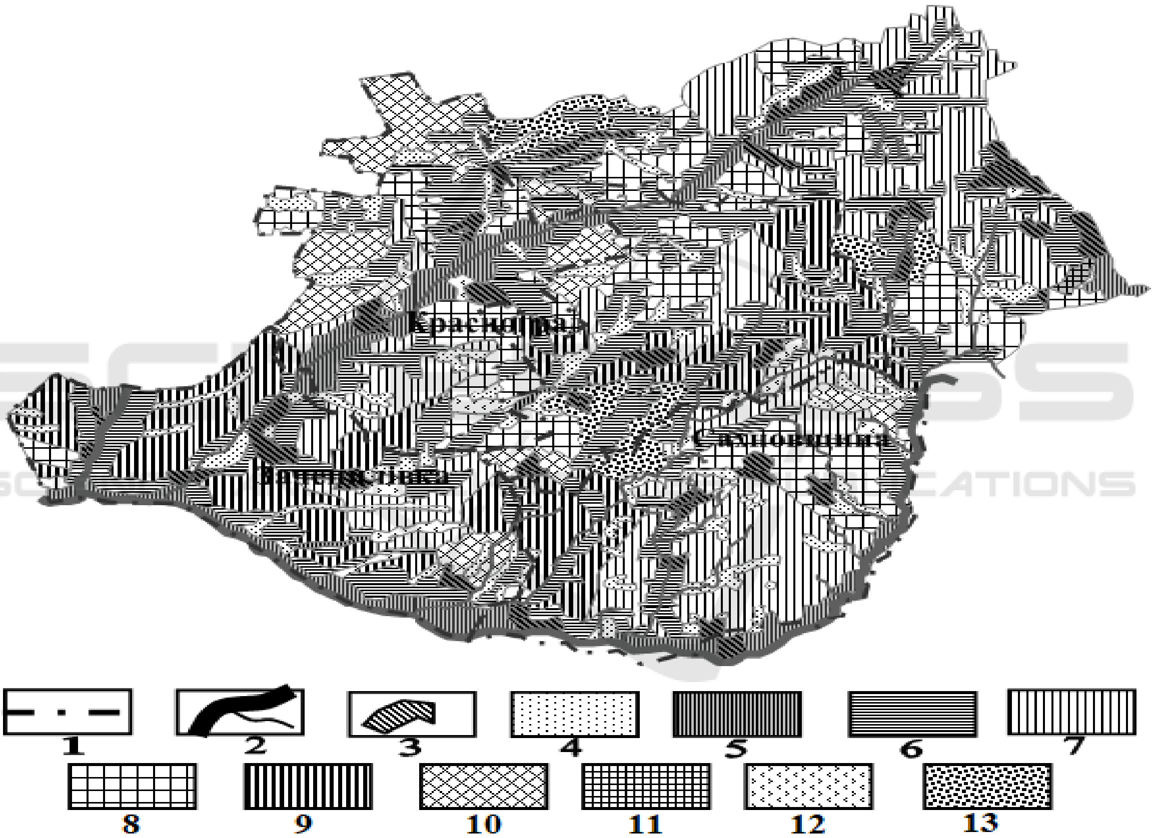
Figure 1: Functional land use. manuscript must be appropriately modified (Sonko et al., 2015).

2 METHODOLOGY

The methodology is based on the main provisions of the theory of the biosphere and the theory of biotic regulation, according to which in natural ecosystems with the help of self-regulatory mechanisms a state of stable dynamic equilibrium is formed, which is constantly maintained. Accordingly, it is necessary to create ecologically tolerant agroecosystems in which the main material and energy mechanisms are close to natural analogues.

The basis of the methodological substantiation of the author's developments is the scientific position of modern synergetics on the invariance of relations in natural ecosystems. In fact, the biosphere independently eliminates anthropogenic impacts on natural ecosystems, which are carried out in the process of agricultural activity (Arskiy et al.,1997), (Sonko et al., 2019). "Incorporation" of specialization of individual farms in natural landscapes (in particular, in the context of climate change) is designed to reduce the negative anthropogenic impact on natural ecosystems.

The main circumstance, allowing us to differentiate between "fodder" and "commodity" arable land, is the fact that all crops of perennial grasses are tied to slopes above 5° as part of soil protection and forage crop rotations (Fig. 2)



Symbols: 1-administrative borders; 2 rivers; 3-settlements; 4-plots of hayfields and pastures on floodplain meadows (consumer area); 5-pastures for cattle grazing in the warm season, selective mowing (area of consumers); 6-year-old grasses (35-40%), winter wheat (25-30%), barley (10-15%); 7-row crops (50-55%), of which corn (15-20%), sugar beet (15-20%), sunflower (10-15%), winter wheat (30-35%), pure fallow (up to 10%), cereals; 8- is the same as 8, only with a larger share of fallow land; 9-row crops (50-55%) ,of which corn takes (20 -25%), sugar beet (10-15%), sunflower (up to 15%), winter wheat (20-25%), pure fallow (10%); 10th is the same as 9, only with a larger share of fallow land (10-13%); 11-vegetable crops (70-75%), winter wheat (up to 10%), cereals (up to 10%), corn (up to 10%); 12-gardens, berries; 13-systems of agriculture, using fertilizers with over 500 kg of active substance per 1 ha of arable land.

Figure 2: Formation of energy flows in agroecosystems (fragment) commercial crops (winter wheat, sugar beet, sunflower) (Sonko et al., 2015).

An interesting phenomenon that to some extent "describes" trophic relations in agroecosystems is the impact of market relations. We know that foreign grain traders regularly "reject" a significant part of marketable grain (up to 30%) exported from Ukraine, lowering its category from commodity to fodder (Kuzmin, 2021), (Cherednichenko, 2020).

In our opinion, a logical explanation for this is in the subject area of agricultural landscapes. It is a fact, that there is a constant removal of nutrients with fluvial flows on the slopes of the landscapes over 3º, and even higher than 5º, which causes gradual reduction of gluten in the grain. So, this is a consequence. We deal with natural regulation of trophic relations in agroecosystems. Knowing the location of agro-landscapes with slopes over 3-5º, you can calculate both the total (gross) amount of fodder grain and the total area of forage crops in the opposite direction (due to average yield), and, consequently, the "area" of secondary consumers. This is where the need to calculate the actual area of forage arable land arises.

By the actual forage arable land we mean the part of the crop rotation area where fodder crops are sown (according to reports) plus the areas occupied by cereals on slopes over 3o and transferred to the rank of forage due to gluten reduction (Fig. 3,4). To calculate the actual forage arable land, we used the formula:

$$Aa.f = Af + Ac * K \tag{1}$$

Here: Aa.f.- actual area under forage crops;

Af - reporting area under forage crops;

Ac - reporting area under cereals;

K - is the residual coefficient (calculated on the example of typical farms and is 0,54 for forest-steppe, 0,49 for steppe, 0,39 for suburban farms).

Joint analysis of the maps "Correlation between energy flows of producers and consumers" (Fig. 3) and "Formation of energy flows in agro-ecosystems" (Fig. 2) revealed a number of features.

Thus, with the existing nature of land use, relatively high marketability was in the types with intensive crop production. It is important to note that as the area of soil-protective crop rotations is large, it is better to sow only cereals and grasses on the slopes due to the greater erosion risk of row crops. The quality of grain obtained from the slope on washed soil is much lower than grain grown on plakor, and corresponds more to fodder than commercial varieties (Svitlychnyi and Chornyi, 2007).

We call the area occupied by fodder crops statistical, considering its fragmentation and the ability of soils to determine the fodder or marketable quality of products, depending on the erosin degree. The areas on slopes with a slope exceeding 5 ° are called potential (Fig.1). The map "Formation of energy flows in agroecosystems" (Fig. 1) shows the potential areas.

The degree of discrepancy between the statistical and potential areas of arable land occupied by forage crops (Fig. 1) can determine the rational use of natural resources of the territory for fodder production. This ratio can be expressed by the following formula:

$$Cf. = A.f.st / A.f.p \tag{2}$$

Here: Cf - coefficient of fodder land use;

A.f.st - statistical area of arable land occupied by fodder crops;

A.f.p. - potential area of arable land occupied by fodder crops.

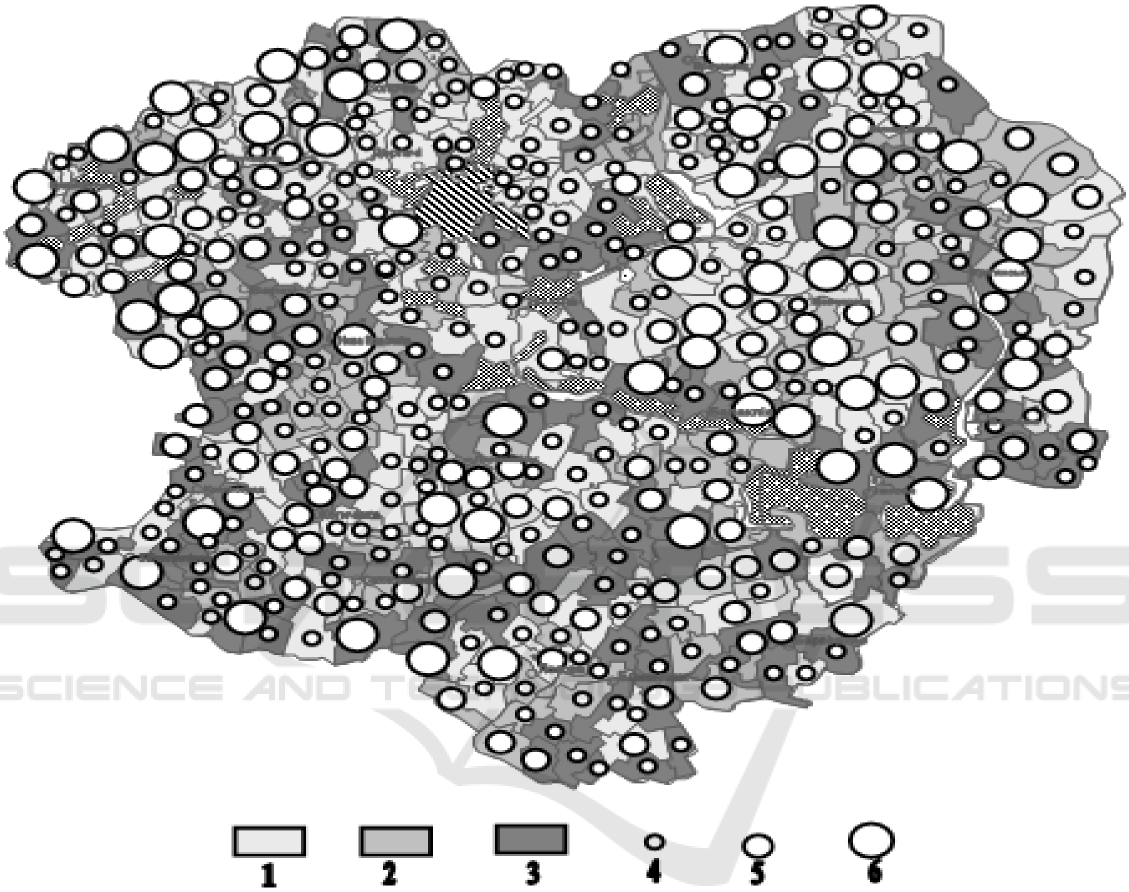
The dependence expressed by this formula can be defined as follows: the higher the coefficient Cf, the worse the use of potential forage arable land is, and the lower the real marketability of crop production in this farm. Today's market economy largely confirms this conclusion, as farms (both private and semi-state) are forced to develop specialization that is very far from the optimal for this agroclimatic potential (The World Bank, 2021), (Buck et al., 2021).

3 RESEARCH RESULTS

Using the above model to calculate the statistical and potential area of arable land occupied by forage crops, we should keep in mind that the coefficient of forage use of arable land was calculated without considering agronomic features, expressed in the need to apply crop rotation. No matter how high the marketability of maize for silage and green fodder is, it should still be included in the crop rotation as a precursor.On the other hand, it is impossible to sow grain corn on the slopes as a row because of the high erosion risk (Kaminskyi et al., 2018).

It is possible to comply potential and statistical areas of arable land under fodder crops with subsequent reduction of fodder use of arable land by improving farming systems on the slopes. Fodder grasses can replace corn for silage or we can replace row corn cultivation with continuous sowing technology. This makes room in watershed crop rotations for row crops and cereals, but with already known product quality. We should note that such a measure does not contradict basic methods of anti-erosion system of agriculture and economic interests of fodder production. Forage grasses, having a strong root system, fix the slope well and, at the same time, are a reliable equivalent of corn for silage, while remaining cheaper to produce.

Table 1 shows the calculation of the fodder use coefficient. Comparing the values of the coefficient with the data of the map "Deformation of energy relations in agro-ecosystems" (Fig. 4) allows us to draw the following intermediate conclusions: the maximum conditional "return" of areas under fodder crops due to concentrated fodder (30%) coincides with the areas with the highest yields and long-term gross harvest of cereals.The value of the coefficient varies according to the economic and natural features of the territory.



Symbols: Share of crop products used in animal husbandry (1985): 1 - below 70%; 2 - 70-75%; 3 - above 75%. Gross crop production, thousand tons: 4 - less than 5; 5 - 5 -7; 6 - more than 7.

Figure 3: Relationship between energy flows of producers and consumers (Sonko et al., 2015).

Thus, in the 1st landscape area the value of Cf is the average in the region due to high grain yields but not optimal (different from 1 by two orders of magnitude) due to large areas of sloping lands tied to medium-washed soils (up to 25%).

In the 2nd landscape area Cf = 2,234 is explained by growing erosion due to specific hydrographic network (small strongly winding watercourses) and the decrease in the possibility of tillage with agricultural machinery. The area of sloping lands is the same as in the first district, but the gross fees from grain production are lower compared to 1 district.

Table 1: Coefficient of fodder use of arable land (Cf) for 10 landscape areas.

№ area	Cf 2	№ area	Cf
1	3,142	6	3,743
2	2,234	7	1,792
3	5,181	8	6,015
4	4,388	9	2,368
5	2,607	10	2,005

In the 8th district Cf - 6,015 is the highest value in the region. It is explained by the minimum areas under the sloping lands (7-10% in the area of arable land) and the need to sow fodder crops in watershed crop rotations. At the same time, the conditional "return" of sown areas under cereals is lower in farms located in the floodplains of the Berestov and Oril rivers due to the use of natural forage lands tied to the floodplains of these rivers.

Therefore, a characteristic feature that combines the 1st, 2nd and 3rd landscape areas is a significant conditional "return" (27-30%) of areas under cereals in favor of fodder.

Given the high economic value of these areas for the production of cereals for food varieties (yield over 5 t / ha) it is necessary to state the need for a clearer justification of the production profile of livestock in order to bring the real marketability of crops in line with agricultural landscapes.

Symbols: The share of conditionally "returned" sown area in the total sown area of cereals in favor of consumers. 1 - under 24%; 2 - 24-27%; 3 - 27-30%; 4 - over 30%.

Figure 4: Deformation of energy relations in agroecosystems (Sonko et al., 2015).

The minimum conditional "return" of areas under fodder crops due to concentrated feed (less than 24%) coincides with the boundaries of the floodplain-suburban area. This is due, firstly, to the significant (up to 48%) areas of fodder crops needed to maintain the dairy population; secondly, to low efficiency of grain production in the floodplain-suburban area.

Cf fluctuations are quite significant - from 5,131 in the third landscape area to 2,607 in the fifth, and 3,747 in the sixth. High value of the coefficient in the third district is due to the large share of sloping lands (27-30%). As part of soil protection, crop rotations of winter wheat occupies 30-35% of the area. The real marketability of crop production reduces as there is no need to occupy large areas for vegetable crops (gross crop production is about twice lower than in the 1st and 2nd forest-steppe areas.

In the 5th and 6th districts Cf is approaching the regional average. Its decrease in comparison with the 3rd district is caused by similar reasons, which is expressed in better use of natural resources of the territory for livestock. Accordingly, pastures occupy a significant share in the composition of feed in the farms on these territories: for the dairy group 15-18%, for cattle for fattening 20-25%. Despite the strong fragmentation (the area of sloping lands reaches 27-30% of the arable land), the watersheds of field crop rotations are better suitable for commercial crop production. This is confirmed by the analysis of crop rotation saturation.

Perennial grasses (40-45%), barley (20-25%), annual grasses (up to 50%) are sown on these slopes. Of the cereals, only fodder barley grows here. Accordingly, the share of green fodder increases up to 30% in the composition of stall animals in the farms in these districts.

Steppe areas 4, 7, 9, 10 are united by conditional "return" of areas under fodder crops. Here, their share is less than 25%. In most cases, this is due to a decrease in yield to 2-2.5 t / ha. It is important that Cf decreases to 2-2,5 here, and in the 7th district it is the lowest in the region, coming to 1,792. This is because crop rotations are mainly used for the production of green fodder in the steppe areas, and the fodder cereals sown there correspond to the fodder quality.

The main differences between natural and agroecosystems are:

1) agroecosystems receive auxiliary energy that is under human control; this auxiliary energy comes in the form of muscular efforts of man and animals, fertilizers, pesticides, irrigation water, the operation of machines running on fuel, etc .;

2) in agroecosystems the diversity of organisms is sharply reduced (also due to human activities that strive for monoculture);

3) dominant species of plants and animals in the agro-ecosystem are subject to artificial rather than natural selection. In other words, the organization and management of the agro-ecosystem is ensured in such a way as to obtain the greatest amount of food. At the same time, certain benefits are accompanied by some losses: soil erosion, pollution of water bodies by demolished pesticides and fertilizers, high fuel costs, increased sensitivity of the system to changes in weather and pests.

Based on the analysis of morphological differences between natural and agroecosystems, it can be argued that there is no reason to consider the agroecosystem unnatural ("semi-natural", "combined", "artificial", "anthropogenic", "man-made"). The natural mechanisms of biomass production, the ratio of its production to trophic levels, food chains, the presence of producers, consumers and reducers, and even "entry" into the relevant ecological pyramid - all this remains. The only thing that needs to be radically changed in the agro-ecosystem is the spatial essence of the ecotope. It is organized by a man with cunningly made "traps" for space (forage), time (temporary discrepancy between natural and economic boundaries of agroecosystems) and information (forced "spreading" of the gene pool).

According to the results of previous studies, in particular in the Cherkasy and Kharkiv regions, data on the development of specialization, not typical of the forest-steppe zone (Sonko et al., 2019). In particular, rice sowing, growing citrus, grapes. That is, these are industries that require huge energy subsidies and, consequently, those whose economic efficiency is very low. In the development of other industries, the laws of geographical zoning are also violated, resulting in the existing monospecialization in either cereals or oilseeds. This practice leads to the rapid depletion of natural resources of agroecosystems, the direct result of which will be a catastrophic loss of soil natural fertility in the near future.

4 CONCLUSIONS

1. The natural ecosystem, transformed by man into an agroecosystem, differs from natural analogues in the spatial structure of edaphic components (ekonish, ecotopes, habitats). Man consciously creates an ecotope of herbivores, sowing fodder crops. However, while in natural ecosystems the flows of matter and energy with a certain degree of approximation are confined to a specific area, in agroecosystems much of the biomass is alienated from the area and in most cases migrates for consumption many kilometers from where it is produced. The only ecologically significant result of human existence as a biological species is the soil, which is a product of life of producers, consumers and reducers that develop in agroecosystems.

2. Trophic (energy) relations in the artificial agroecosystem are characterized by both complexity and simplicity. The difficulty lies in the artificial material and energy support of monocultures of commercial and fodder crops through application of fertilizers, plant protection products, the use of genetically modified varieties and hybrids. Simplification is the conscious "circumcision" of human trophic pyramids of the domesticated species of plants and animals compared to their wild zonal counterparts.

3. The formation of artificially supported agrophyto- and zoocenoses directly affects the spatial structure of agrolandscapes. According to our methodology, we can identify "habitats" of producers and consumers with a high level of accuracy (depending on the slopes).

4. In the context of climate crisis, the general strategy for the rational formation of agricultural landscapes remains, but the list of forage plants adapted to arid climates will require adaptation measures. In particular, more attention should be paid to drought-resistant crops with C4 type of photosynthesis: sugar cane, corn, miscanthus, sorghum, sundew (effective pasture plant), amaranth, purslane, ivan-tea, marjoram (Dysphania botrys), leafless sedge (Edwards and Walker, 1986), (Afanasyev, 2021). However, these plants are well consumed by cattle, they can be used in cooking and as medicinal plants.

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