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ANALYSIS OF GRASSLAND ANPP DYNAMICS DUE TO CHANGES IN CLIMATE VARIABLES AT UKRAINIAN BIOSPHERE RESERVE 'ASKANIA-NOVA'

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Abstract

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The Ukrainian feather-grass steppe ecosystems are highly vulnerable to climate changes. To study the impact of climatic factors on steppe ecosystems' productivity, the correlation and stepwise regression analysis between ANPP and other variables were provided. The correlation of bioclimatic variables (month precipitation, relative humidity and air and soil temperatures) and above-ground net primary production (ANPP) were investigated for three study plots that represent major steppe microrelief: plain, slope and lowland. The results of multiple regression analysis showed the major components that influenced the ANPP at each of the study plots 'Plain', 'Slope' and 'Lowland'. The precipitation and relative humidity in the months before the vegetation peak were most important for ANPP accumulation.
Results of this study are important for the prediction of ecosystem changes under the climate changes and also for the development of nature conservation programmes.

Key words: ANPP, steppe, grassland, precipitation, relative humidity, air and soil temperatures, correlation, multiple regression analysis.

Introduction

The impact of climate change on different ecosystems is a key issue for their sustainable functioning. As for now, the potential effect of climate change is studied less compared to forest ecosystems. According to Ojima (1993), grassland ecosystems cover about one-quarter of the Earth's terrestrial surface and function in different climate conditions that range from humid to arid climate zones. Grassland is one of the most widespread types of ecosystem and covers nearly 24×10^6 km^2, according to Eswaran et al. (1993). This broad range of climate conditions is a unique base for the studies on grassland C_4 and C_3 coenoses and their interactions with bioclimatic variables, soil contamination, energy flux, anthropogenic factor and many others. Temperate grasslands are represented by a wide range of vascular plants (Wilson et al., 2012). Also, European grasslands, which were formed under different climate conditions, have high level of biodiversity and include a broad spectrum of subzones and ecosystems strongly influenced by the type of land use and agroecosystems spreading. Intense human activity has influenced grassland ecosystems, but a high level of natural plant richness is typical for semi-natural sites that have been mown regularly over long periods (Dengler et al., 2014).

Ukrainian grasslands, also known as Ukrainian steppe, and forest-steppe zones, which are represented by vascular steppe coenoses, cover more than 73% of Ukraine's territory, according to Moysenko et al. (2014). The Ukrainian steppe zone is a part of the Eurasian steppe zone, which was formed before the Pleistocene (Didukh et al., 2003).

The net primary production (NPP) is a key component of ecosystem functioning, and it plays a major role in the flow of energy and shows the balance between chemical energy (gross primary production) produced by ecosystem coenoses and energy, expanded for ecosystem respiration.

NPP is also a component of the global carbon cycle and, according to Lobell et al. (2002), a key indicator of ecosystem performance.

Material and methods

Site characteristics

The study was conducted at the Biosphere Reserve (BR) 'Askania-Nova' of National Academy of Agrarian Sciences of Ukraine named after F.E. Faltz-Fein. This BR is located near Askania-Nova of Chaplinsky district, Kherson region, Ukraine. The area of the reserve is 33,307.6 ha, of which 9,617.0 ha (87% of the natural core) belongs to the virgin steppe, standard for dry fescue–feather grass steppe (Gavrylenko, 2008).

The territory of the BR Askania-Nova belongs to the Eurasian steppe region, Steppe subregion, Pontian steppe province and Dnieper-Azov district of grass, sagebrush-grass and lowland grasslands (Paton et al., 2007). The conducted research was focused on data sets from the model plant communities of ecological study plots 'plain → slope → lowland' of the site 'Stara' (Engl. 'Old'). Site 'Stara' was set up as a protected reserve in 1898 (Fig. 1). It is located in natural core of the BR 'Askania-Nova', which belongs to a water-collecting area of the Great Chapelsky lowland. Plains are situated in the central part of site 'Stara', and the slopes are mainly located in the western part of it.

Southern Steppe areas of Ukraine are mainly characterised by low relative air humidity and high air temperatures during summer months. The average temperature of the air ranges from −1.5 to −5 °C in January and 23–24 °C in July; the average annual air temperature is +9.4 °C. The average annual mean precipitation is 300–450 mm with a large annual range of 180–690 mm; for example, in 2011, the amount of precipitation was 240.3 mm, but it ran up to 688.4 mm in 1997, the average annual mean precipitation for the period 1996–2014 was 422.4 ± 30.98 mm. Drought seasons can last for more than 40 days, which is why modelling of precipitation changes given raised by climate processes, is one of the main issues of our study (Gofman, 2014; Lipinsky, 2003).

The bedrocks of Ukrainian Steppe are loess-like, alluvial, lake, salt, deluvial, proluvial formations. The peculiarity of the organic matter steppe vegetation decomposition determines the soil-forming processes in the zone of the Askanian Steppe (Gofman, 2014).

The zone has lowlands and minor depressions, typical weak overall slopes and slight land dismemberments. Dark chestnut residual saline soils are located on plains (73.9 %); the slopes, in turn, have dark chestnut saline soils and saline (7.4%). Grassland-chestnut soils (7.2%) and gleyic soloths (1.4%) formate lowlands. One of the features of the Askanian Steppe is the deep occurrence of groundwater, which varies from 11 to 23 m in depth (Hudz et al., 2014).

The model plant communities of ecological line 'plain → slope → lowland' of site 'Stara' are fescue-feather grass plain group (*Stipa ucrainica* L. (+ *S. capillata, S. lessingiana*) + *Festuca valesiaca* L.), spring sedge narrow-leaved June

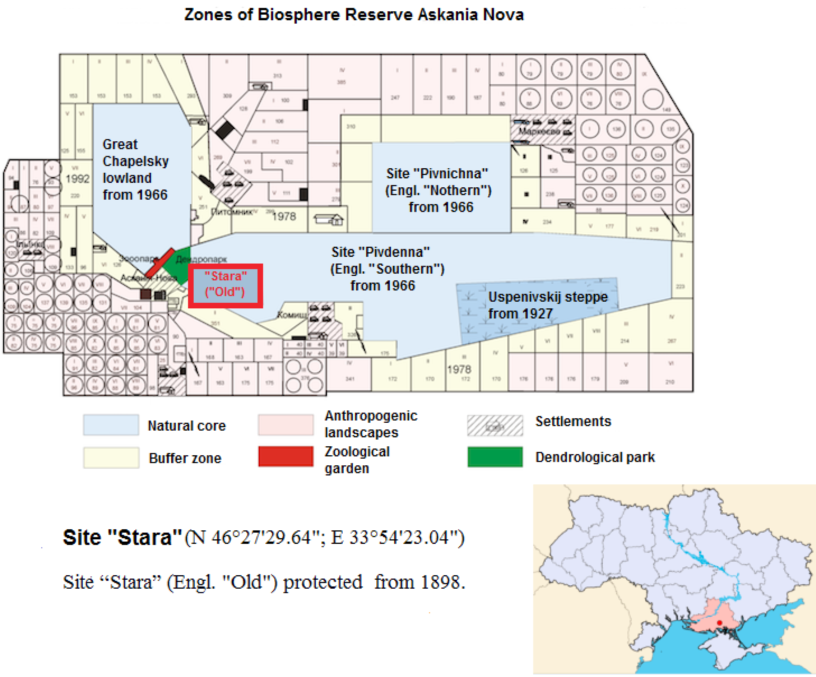

Fig. 1. The geographical location of site "Stara".

grass slope group (*Poa angustifolia* L. + *Carex praecox* L.), intrazonal wheat grass and narrow-leaved June grass lowland group (*Poa angustifolia* L. + *Elytrigia pseudocaesia* L.) (Gofman, 2014; Dobracheva et al., 1987).

During the period 1996–2012, the average stock biomass of plain vegetation totalled 292.0 ± 15.25 g/m^2. For mass-dominant stands, firm-bunch grass such as *Stipa ucrainica, Festuca valesiaca* L. and *Koeleria cristata* (L.) Pers. and herbs such as *Galatella villosa* (L.) Rchb. f., *Galium ruthenicum* Willd. and *Carduus uncinatus* M. Bieb. dominate. A fraction of therophyte plain plants has significant changes in mass percentage (it significantly increases during wet years) from year to year. Therophyte plant species are usually represented by plant dominants such as *Cerastium ucrainicum* Pacz. ex Klokov, *Holosteum umbellatum* L., *Myosotis micrantha* Pall. ex Lehm., *Valerianella costata* (Steven) Betcke, *Veronica verna* L.

The dominant slope species, as for 1996, for mass and multiplicity was firm-bunch grass, such as *Stipa capillata* L., *S. ucrainica* L., *Festuca valesiaca* L., and *Koeleria cristata* L. In 2003, the ratio of the mass of firm-bunch grass to the rhizomatous grass fractions was 6.6–1.0. In the year 2004, the situation has changed, the mass of rhizomatous grass has significantly increased and firm-bunch grass mass has sharply decreased: the ratio was 1.0–1.4. In 2005, the ratio was even more impressive – 1.0–8.6. During the subsequent years, the part of rhizomatous grass mass continued to grow.

Slope Grassland plant communities are characterised by increased succession activity with domination of rhizomatous species such as *Poa angustifolia* L. and *Carex praecox* Schreb. (Shapoval, 2012) and indicated the prevalence of grassland phytocoenosis on the site 'Stara'. The area occupied by grassland and steppe plant communities is 32.6% (169.7 ha) and 29.0% (150.8 ha), respectively.

A possible factor in the accelerated mesophytisation process of plant groups is a powerful mulch reserve acting as a hydrothermal buffer. This buffer facilitates an optimal redistribution of atmospheric moisture in the humus horizon (Gofman, 2014; Shapoval, 2012).

The dominating species of intrazonal lowland plant communities by weight and abundance are *Poa angustifolia* L., *Carex melanostachya* M. Bieb. ex Willd., *Elytrigia pseudocaesia* (Pacz.) Prokud. A powerful mulch layer of the lowland greatly suppresses the floristic diversity and abundance of therophyte herbs. Lowland perennial herbs are represented by the same species that are found on the slope (Gofman, 2014).

Data sources and sample procedures

Data on above-ground net primary production (ANPP) were obtained from the annual reports from BR 'Askania-Nova', called 'Annals of Nature' (ukr. – 'Litopys pryrody'), for the period 1949–2012 and authors' field data for the years 2013–2015.

Meteorological data were collected from 1949 till 2015 at the meteorological station in Askania-Nova, including total monthly precipitation for January–December, annual precipitation, total precipitation for the autumn–winter–spring period (AWSP), sum precipitation for 12 months before vegetation peak (12MBVP; last week of June – first week of July), monthly soil temperature, average and lowest annual temperature, monthly air temperature, average annual temperature and monthly and annual relative humidity.

The archival data on ANPP and related parameters, such as phytomass and mortmass, at three study plots 'plain → slope → lowland', which represent different microrelief and ecosystem conditions, at study site 'Stara', BR 'Askania-Nova', were used in the study. Data for the study plot 'slope' were collected for the years 1996–2012; 'Lowland' for the years 1949–1961, 1966–1970 and 1996–2012; and 'Plain' for the years 1949–1961, 1966–1970, 1977–1980 and 1983–2012. Field data for 2011–2016 years were collected by authors.

It is necessary to note that monthly, sum and average data were regrouped, according to the vegetation peaks in study plots. The main vegetation peak in 'Plain' and 'Slope' is in June, and in 'Lowland', it is in May. So, all variables linked to the period July–December were taken from the previous year, because we tried to investigate linkages of bioclimatic variables and how they impact ANPP. It was shown that precipitation in December 2010 resulted in the ANPP peak in June 2011.

Above-ground biomass has been picked out by the cut-sample method during the dominant species vegetation peak (25th of June to 15th of July). Samples were taken in the plots (0.5 m^2) five times randomly. The selected cut-sample mass was separated into biomass and mortmass fractions. Later, knotweed plants evolved from the biomass the therophyte and perennial herbs, sedges, grasses; in turn, the mortmass was partitioned into dead plant material and mulch.

Using counterbalance, the samples were weighed in air-dry conditions within the accuracy of 0.1 g. The NPP was determined as the difference between biomass and mortmass.

Statistical analysis

Obtained historical ANPP and methodological data sets were tested for normality using the Kolmogorov–Smirnov and the Shapiro–Wilk tests.

The data sets were subjected to correlation analysis in IBM SPSS Statistics program (version 24) to detect the statistical inter-relations between ANPP and meteorological factors that may affect it; for this purpose, a Pearson coefficient was chosen. The strength of correlation coefficient was assessed by the guide that Evans (1996) suggests for the absolute value of r:

- 0.00–0.19: 'very weak'
- 0.20–0.39: 'weak'
- 0.40–0.59: 'moderate'
- 0.60–0.79: 'strong'
- 0.80–1.0: 'very strong'.

All meteorological variables were used in multiple linear regression analysis (stepwise regression) as independent variables to investigate their influence on ANPP accumulation. Created regression models were checked for the presence of autocorrelated deviations using the Durbin–Watson statistics.

Results and discussion

The testing of ANPP normal distribution

The first step was to combine ANPP data from all study plots and check them for normal distribution (Fig. 2), to confirm or reject similarity of ANPP data between plots. The histogram in Fig. 2 showed non-normal distribution with two peaks, describing two different tendencies of ANPP accumulation (first peak ranges from 0 to 600 g/m^2, second one ranges from about 600 to almost 1,300 g/m^2).

The second step was to create a box-plot diagram, to investigate which data were outliers for this particular distribution (Fig. 3).

The cases described on the graph as outliers belong to 'Lowland' ANPP for 1998–2012. This difference could be explained by biodiversity changes that resulted in ANPP growth. The explanation of this could be in microrelief of the Great Chapelski lowland, which is a natural reservoir for precipitation. This causes additional soil moisture and increases primary productivity of plant coenoses. According to the current periodicity, Chapelski lowland was flooded in 1996, which could explain how plant species changes to more productive coenoses. This hypothesis requires additional research on the influence of post-flooding processes on ANPP and plant species composition.

According to ANPP difference between study plots, for the next analysis, data were divided based on location into three data sets. ANPP data sets were tested for normal distribution using the Kolmogorov–Smirnov and the Shapiro–Wilk tests. All tests proved normal distribution of NPP

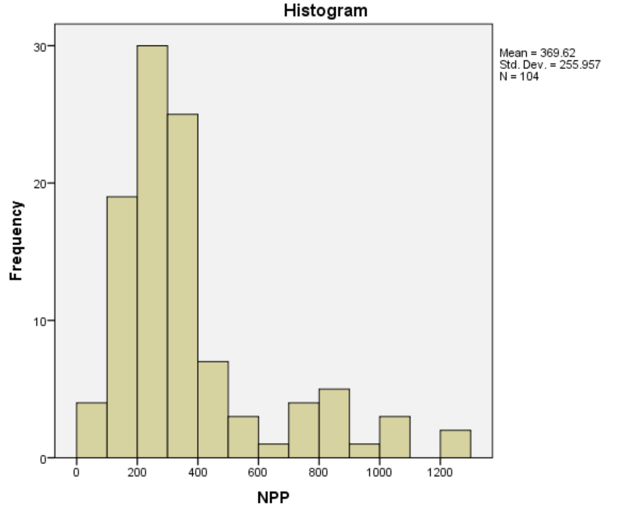

Fig. 2. The distribution of ANPP of steppe coenoses at Slope, Plain and Hollow study plots.

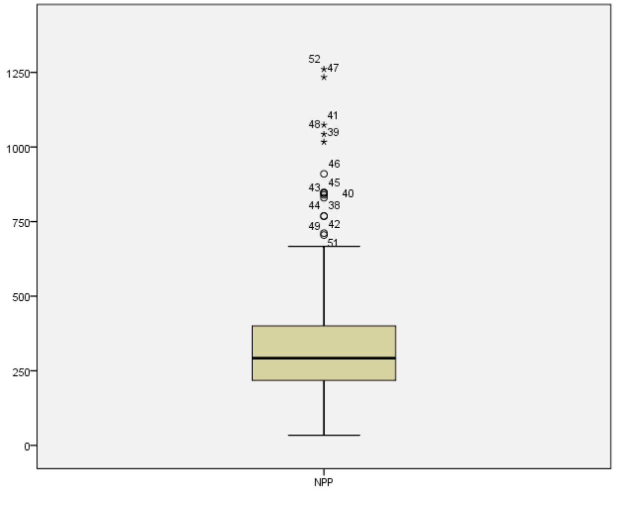

Fig. 3. The box-plot for ANPP distribution of steppe coenoses at Slope, Plain and Hollow study plots.

data and explained that data sets could be included into multiple regression analysis as a dependent variable.

Correlation analysis of variables from study plot 'Plain'

In the study plot 'Plain', data sets showed significant moderate correlation of NPP with sum precipitation for 12 MBVP ($r = 0.56$, $p < 0.01$) and AWSP ($r = 0.55$, $p < 0.01$), year ($r = 0.51$, $p < 0.01$), relative humidity in August ($r = 0.47$, $p < 0.01$) and precipitation in October before vegetation peak ($r = 0.45$, $p < 0.01$) (Table 1). It showed weak correlation with precipitation in April ($r = 0.39$, $p < 0.01$), relative humidity in June ($r = 0.38$, $p < 0.01$) and average soil temperature of 12MBVP ($r = 0.35$, $p < 0.05$).

It showed negative correlation with relative humidity in January ($r = -0.34$, $p < 0.05$), May ($r = 0.30$, $p < 0.05$), relative humidity in July ($r = 0.34$, $p < 0.05$) and October ($r = 0.29$, $p < 0.05$); precipitation in March ($r = 0.33$, $p < 0.05$), August ($r = 0.32$, $p < 0.05$) and December ($r = 0.32$, $p < 0.05$); and soil temperature in July ($r = 0.30$, $p < 0.05$).

T a b l e 1. Correlation matrix of ANPP and climate variables at study plot 'Plain'.

Variables correlated with ANPP	**Pearson's correlation coefficient, r**	**Significance, p**	**Sample size, n**
Year	0.51**	0.00	48
Precipitation in March	0.33*	0.02	48
Precipitation in April	0.39*	0.00	48
Precipitation in August	0.32*	0.03	47
Precipitation in October	0.45**	0.00	47
Precipitation in December	0.32*	0.03	47
Sum precipitation in AWSP	0.55**	0.00	47
Sum precipitation in 12MBVP	0.56**	0.00	47
Soil temperature in July	0.30*	0.04	45
Average soil temperature for 12MBVP	0.36*	0.02	44
Relative humidity in January	−0.34*	0.02	48
Relative humidity in May	0.30*	0.04	48
Relative humidity in June	0.38*	0.01	48
Relative humidity in July	0.34*	0.02	48
Relative humidity in August	0.47**	0.00	48
Relative humidity in October	0.29*	0.05	48
Average relative humidity for 12MBVP	0.42**	0.00	48

Notes: * - 'Weak', ** - 'Moderate', *** - 'Strong', **** - 'Very strong'.

Regression analysis of variables from study plot 'Plain'

A multiple stepwise regression model equation described the links between dependent variable ANPP and independent variables. The model was built with parameters for 47 years

(N = 47). The model equation quality was estimated using the coefficient of determination, the significance coefficient and the Durbin–Watson test ($R^2 = 0.68$, $p < 0.05$, DW = 1.7, SE = 50.18).

ANPP ('Plain') = −2,701.437 – 0.486 * (Sum precipitation for 12MBVP) + 1.303 * (Year) + 1.026 * (Precipitation in April) + 2.458 * (Relative humidity in June).

Correlation analysis of variables from study plot 'Lowland'

For the study plot 'Lowland', data sets showed significant, very strong correlation of NPP with Year ($r = 0.86$, $p < 0.01$), that is, the evidence of year trend of ANPP (Table 2).

It showed strong correlation with air temperature in March ($r = 0.61$, $p < 0.01$); average soil temperature for 12MBVP ($r = 0.60$, $p < 0.01$); soil temperature in March ($r = 0.44$, $p < 0.05$), July ($r = 0.45$, $p < 0.05$), August ($r = 0.44$, $p < 0.05$) and September ($r = 0.60$, $p < 0.01$); precipitation in March ($r = 0.46$, $p < 0.01$); and average air temperature for 12MBVP ($r = 0.46$, $p < 0.01$) .

It showed negative correlation with relative humidity in December ($r = -0.44$, $p < 0.05$), March ($r = -0.44$, $p < 0.05$) and January ($r = -0.36$, $p < 0.05$) and positive correlation with air temperature in April ($r = 0.37$, $p < 0.05$).

T a b l e 2. Correlation matrix of ANPP and climate variables at study plot 'Lowland'.

Variables correlated with ANPP	**Pearson's Correlation coefficient, r**	**Significance, p**	**Sample size, n**
Year	0.86****	0.000	32
Precipitation in March	0.46**	0.008	32
Soil temperature in March	0.44**	0.018	28
Soil temperature in July	0.45**	0.015	28
Soil temperature in August	0.44**	0.020	28
Soil temperature in September	0.60***	0.001	27
Average soil temperature for 12MBVP	0.60***	0.001	24
Air temperature in March	0.61***	0.000	32
Air temperature in April	0.37*	0.036	32
Average air temperature for 12MBVP	0.46**	0.008	31
Relative humidity in January	−0.36*	0.042	32
Relative humidity in March	−0.44**	0.012	32
Relative humidity in December	−0.44**	0.012	32

Notes: * - 'Weak', ** - 'Moderate', *** - 'Strong', **** - 'Very strong'.

Regression analysis of variables from the study plot 'Lowland'

In addition, a multiple stepwise regression model was created, describing the links between dependent variable ANPP and independent variables. The model was built with parameters for 28 years

(N = 28). The model equation quality was estimated using the coefficient of determination, the significance coefficient and the Durbin–Watson test ($R^2 = 0.95$, $p < 0.05$, DW= 1.37, SE = 87.59).

The ANPP ('Lowland') = −27,087.083 + 13.463 * (Year) + 42.646 * (Soil temperature in April) + 2.666 * (Precipitation in July) + 17.252 * (Relative humidity in August) + 16.036 * (Air temperature in January).

Correlation analysis of variables from study plot 'Slope'

The ANPP data set for the study plot 'Slope' showed strong positive correlation between NPP and sum precipitation for 12 MBVP (r=0.76, p<0.01) and the AWSP (r = 0.70, p < 0.01) before vegetation peak and with average humidity for 12MBVP (r = 0.67, p < 0.01) (Table 3).

It showed moderate positive correlation with relative humidity in July (r = 0.56, p < 0.05) and precipitation in December (r = 0.52, p < 0.05) and moderate negative correlation with year (r = −0.58, p < 0.05) and air temperature in October (r = −0.53, p < 0.05) and September (r = −0.53, p < 0.05).

T a b l e 3. Correlation matrix of ANPP and climate variables at study plot "Slope".

Variables correlated with ANPP	**Pearson's Correlation coefficient, r**	**Significance, p**	**Sample size, n**
Year	-0.58^{**}	0.02	16
Precipitation in December	0.52^{**}	0.04	16
Sum precipitation for AWS	0.70^{***}	0.00	16
Sum precipitation for 12MBVP	0.76^{***}	0.00	16
Air temperature in September	-0.53^{**}	0.04	16
Air temperature in October	-0.53^{**}	0.04	16
Relative humidity in July	0.56^{**}	0.03	16
Average relative humidity for 12MBVP	0.67^{***}	0.00	16

Notes: * - 'Weak', ** - 'Moderate', *** - 'Strong', **** - 'Very strong'.

Regression analysis of variables from the study plot 'Slope'

Regression analysis showed the dependence of ANPP from the study plot 'Slope' on relative humidity in November, air temperature in February and December, but because of the small sample size for this plot, this result could only be used with some limitation. The model was built with parameters for 16 years (N = 16). At the same time, the year was not included into the equation; because of the small sample size, the year trends. The model equation quality was estimated using the coefficient of determination, significance of coefficients and the Durbin–Watson test ($R^2 = 0.99$, $p < 0.05$, DW = 2.54, SE = 9.29), but the high coefficient of determination could be the result of small sample size.

ANPP ('Slope') = −2,281.525 + 29.935 * (Relative humidity in November) + 21.317 * (Air temperature in February) + 5.391 * (Air temperature in December).

The response of steppe ANPP to precipitation changes at study plot 'Plain'

The dominant plants of the study plot 'Plain' were represented by rhizomatous species, such as *Elytrigia pseudocaesia* L., *Poa angustifolia* L., *Carex melanostachya* L. and *C. praecox* L.

The available data sets for this plot included 47 inputs, which is the reason why 'Plain' is the most interesting study plot for yearly trends and correlation investigation.

For the study plot 'Plain', data sets showed significant moderate correlation with ANPP and year ($r = 0.52$, $p < 0.01$), which is the evidence of a linear trend in vegetational processes.

The first large group of variables that correlate with ANPP is represented by precipitation.

The presence of moderate and weak correlation of ANPP and precipitation during spring months (March and April) showed the importance of these months for ANPP accumulation. There are moderate and weak correlations of precipitation in October and December, which suggests a dependence of ANPP from precipitation during the winter period. Also, the sum precipitation of both AWSP and 12MBVP moderately correlates with ANPP, which shows the role of precipitation during the pre-vegetation period.

The role of soil temperature was proved by correlation with average soil temperature for 12MBVP. In addition, soil temperature during the vegetation peak month correlates with ANPP.

The second large group of variables are presented by relative humidity for January, May, June, July, August and October and average humidity for 12MBVP. So, ANPP of plant conenoses 'Plain' study plot is more sensitive to humidity changes.

The regression analysis showed the dependence of ANPP on spatial precipitation in April and relative humidity in June. This can help to prove that the precipitation and relative humidity in the months before the vegetation peak are important for ANPP accumulation.

Also, the year was included in the model equation to prove the presence of linear trends in changes in production at 'Plain' study plot. For future predictions of ANPP, the time series analysis can be used (trends, ARIMA, etc.).

The equation can also be used for future ANPP estimation and can help to investigate coefficients to measure the role of these variables.

The response of steppe ANPP to precipitation changes at the study plot 'Slope'

The microrelief of the 'Slope' study plot is not typical steppe relief. The plant composition at this study plot is represented by dominant species such as *Poa angustifolia* L. and *Carex praecox* L.

The ANPP negatively correlated with year, which could be the evidence of changes in plant diversity (as of now, the production has decreased).

Sum precipitation for AWSP and 12MBVP were important for NPP growth and, in addition, precipitation in December.

Air temperature in September and October influenced the processes of future ANPP accumulation. Air temperature plays a role in additional storage of mortmass and nutrient accumulation, which will be used for vegetation peak of the next year.

The average relative humidity and relative humidity during the vegetation peak month also play a role in ANPP accumulation.

The response of steppe ANPP to precipitation changes at study plot 'Lowland'

The available data set for the 'Lowland' study plot included 28 inputs, which makes it the second largest complete data set ready for analysis. Lowland presents the second different type of steppe microrelief that differs in plant composition. It is represented by dominant species such as *Poa angustifolia* L. and *Elytrigia pseudocaesia* L. The ANPP of this study plot had very strong linear correlation with year of study, which is the evidence of linear trend of NPP dynamics. The precipitation had correlation with ANPP only in March. The largest group of variables was linked to soil temperature in the pre- and post-vegetation (March, July) periods and to the average soil temperature for 12MBVP.

The air temperature variables during the spring pre-vegetation peak period correlate with ANPP, and average air temperature for 12MBVP also influences the production processes at the study plot.

The correlation of relative humidity in winter period (January and December) with next year ANPP can be explained by the accumulation of snow in the lowland as additional stock of moisture.

The regression analysis showed the dependence of ANPP on soil temperature during the pre-vegetation peak period (April) and air temperature in January (this could be linked with relative humidity dependence from the previous analysis and proves the importance of snow accumulation for plant growth). Also, the regression analysis showed the presence of linear trends with year as independent variable.

The response of steppe ANPP to precipitation changes

Previous studies on ANPP showed both linear and non-linear response to precipitation changes, depending on the grassland's ecosystem type (Hijmans et al., 2005; Lauenroth, Sala, 1992; Paruelo et al., 1999; Ponce Campos et al., 2013). This result was confirmed by our previous studies on the relations between ANPP and precipitation (Belyakov et al., 2017), which showed both a linear and a non-linear response of ANPP under precipitation changes. According to the results of the previous study, which included data sets from 'Plain' study plot, the linear regression model of ANPP and sum precipitation for AWSP ($R^2 = 0.30$, $p = 0.05$) and non-linear, quadratic regression model of the same parameters ($R^2 = 0.36$, $p = 0.05$) had similar significance levels. The modelling of dependence of ANPP from sum precipitation for 12MBVP showed similar results (linear: $R^2 = 0.35$, $p < 0.05$; quadratic: $R^2 = 0.42$, $p < 0.05$). (Belyakov et al., 2017). Data set from previous study covered for the years 1988–2012, so current study included more broad set of measurements and is more accurate. The results of the current analysis showed a linear response of ANPP to sum precipitation during the AWSP and 12MBVP at the 'Plain' and 'Slope' study plots. For the study plot 'Lowland', the correlation was only with precipitation in March when the vegetation peak for the dominant species of this plot was observed. The result was that the 'Lowland' study plot ANPP has less sensitivity to precipitation changes.

The estimation of non-linear response of ANPP to temperature, precipitation and humidity will be the next step of investigation.

Available studies on grasslands NPP modelling (Webb et al., 1978; Sala et al., 1988; Schuur, 2003; Del Grosso et al., 2008) proved linkages between the accumulation of NPP and changes in precipitation, air and soil temperatures in forest and forest-plant and plant ecosystems, with more close relation of ANPP and temperature in forests and ANPP and precipitation in grassland ecosystems.

Conclusion

The results of this study showed that the pre-vegetation period plays an important role in future ANPP accumulation in steppe ecosystems.

The ANPP also depends on relative humidity during the winter period, this helps to accumulate snow as an additional source of water. At the same time, annual precipitation is poorly correlated with ANPP, and it is the evidence of non-linear response of ANPP to precipitation changes. The ANPP can also be predicted using time series analysis. This is a good opportunity for future studies.

Results of this study are important for the prediction of changes in ecosystem under the climate changes and also for the development of nature conservation programmes.

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References

Belyakov, S.O., Gofman, O.P. & Vyshenska I.G. (2017). Modelling the dynamics of total precipitation and aboveground net primary production of fescue-feather grass steppe at Askania Nova according to global climate change scenarios. *Biosystems Diversity*, 25(1), 16–24. DOI: 10.15421/011703.

Del Grosso, S., Parton, W., Stohlgren, T., Zheng, D., Bachelet, D., Prince, S., Hibbard, K. & Olson R. (2008). Global potential net primary production predicted from vegetation class, precipitation, and temperature. *Ecology*, 89, 2117–2126. DOI: 10.1890/07-0850.1.

Dengler, J., Janisova, M., Torok, P. & Wellstein C. (2014) Biodiversity of Palaearctic grasslands: a synthesis. *Agric. Ecosyst. Environ*., 182, 1–14. DOI: 10.1016/j.agee.2013.12.015.

Didukh, Y.P. & Shelyag-Sosonko Y.R. (2003). Geobotanic zoning of Ukraine and adjacent areas (in Ukrainian). *Ukrainian Botanical Journal*, 60(1), 6–17.

Dobracheva, D.N., Kotov, M.Y. & Prokudyn Yu. N. (1987). *Key for determination of vascular plant species of Ukraine (in Russian)*. Nauk. Dumka.

Eswaran, H., van den Berg E. & Reich R. (1993) Organic carbon in soils of the world. Soil Sci. Soc. Am. J., 57, 192–194. DOI: 10.2136/sssaj1993.03615995005700010034x.

Evans, J.D. (1996). *Straightforward statistics for the behavioral sciences*. Pacific Grove: Brooks/Cole Publishing.

Gavrylenko, V.S. (2008). Present regimes of protected steppe in "Askania-Nova" and some results of their influence on saving biodiversity (in Ukrainian). *Nature Reserves in Ukraine*, 14(1), 53–61.

Gofman, O.P. (2014). Correlation of dynamic of aboveground phytomass of vegetation of Askanian steppe is in connection with the quantity of precipitations (in Ukrainian). *Nauk. Zap. NaUKMA. Biologija ta ekologija*, 158, 70–78.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25, 1965–1978. DOI: 10.1002/joc.1276
Hudz, V.P., Shuvar, I.A., Yunyk, A.V., Rykhlivs'kyy, I.P. & Mishchenko Yu. H. (2014). *Adaptive systems of agriculture (in Ukrainian)*. Kyyiv: «Tsentr uchbovoyi literatury».
Lauenroth, W. & Sala O. (1992). Long-term forage production of North American shortgrass steppe. *Ecol. Appl.*, 2(4), 397–403. DOI: 10.2307/1941874
Lipinskiy, V.M., Djachuk, V.A. & Babichenko V.M. (2003). *Climate of Ukraine (in Ukrainian)*. Kyiv: Rayevskyy Publishing House.
Lobell, D.B., Hicke, J.A., Asner, G.P., Field, C.B., Tucker, C.J. & Los S.O. (2002). Satellite estimates of productivity and light use efficiency in United States agriculture, 1982–1998. *Global Change Biology*, 8, 722–735. DOI: 10.1046/j.1365-2486.2002.00503.x.
Moysienko, I.I., Zachwatowicz, M., Sudnik-Wojcikowska, B. & Jabłonska E. (2014). Kurgans help to protect endangered steppe species in the Pontic grass steppe zone, Ukraine. *Wulfenia*, 21, 83–94.
Ojima, D.S., Parton, W.J., Schimel, D.S., Scurlock, J.M.O. & Kittel T.F.G. (1993). Modeling the effects of climate and CO_2 changes on grassland storage of soil C. *Water, Air, Soil Pollut.*, 70, 643–657. DOI: 10.1007/BF01105027.
Paruelo, J., Lauenroth, W., Burke, I. & Sala O.E. (1999). Grassland precipitation-use efficiency varies across a resource gradient. *Ecosystems*, 2(1), 64–68. DOI: 10.1007/s100219900058.
Paton, B.Y., Veklych, L., Gritsenko, P. & Yevropina I. (2007). *National Atlas of Ukraine (in Ukrainian)*. Nat. Acad. Sci. Ukraine "Cartography".
Ponce-Campos, G.E., Moran, M.S., Huete, A., Zhang, Y., Bresloff, C. & Huxman T.E. (2013). Ecosystem resilience despite large-scale altered hydroclimatic conditions. *Nature*, 494, 349–352. DOI: 10.1038/nature11836.
Sala, O.E., Parton, W.J., Joyce, L.A. & Lauenroth W.K. (1988). Primary production of the central grassland region of the United States. *Ecology*, 69, 40–45. DOI: 10.2307/1943158.
Schuur, E.A.G. (2003). Productivity and global climate revisited: The sensitivity of tropical forest growth to precipitation. *Ecology*, 84, 1165–1170. DOI: 10.1890/0012-9658(2003)084%5B1165:PAGCRT%5D2.0.CO;2.
Shapoval, V.V. (2012). *Flora of vascular plants of Askania steppe (in Ukrainian)*. Askanija Nova: FOP Andrjejev O. V.
Webb, W., Szarek, S., Lauenroth, W., Kinerson, R. & Smith M. (1978). Primary productivity and water use in native forest, grassland, and desert ecosystems. *Ecology*, 59, 1239–1247. DOI: 10.2307/1938237.
Wilson, J.B., Peet, R.K., Dengler, J. & Partel M. (2012) Plant species richness: the world records. *J. Veg. Sci.*, 23, 796–802. DOI: 10.1111/j.1654-1103.2012.01400.x.