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Influence of climate dynamics and liming on physicochemical soil properties and crop- rotation productivity of North-Western Polissya in Ukraine

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Abstract

Two liming fertilizers for soil deacidification in Polissya were investigated: dolomite and lime flour, which were applied at the beginning of the 8-year crop rotation with medium fertilizer $N_{112}P_{82}K_{105}$ between 2011 and 2019. The experiments were performed in a stationary field trial by the Institute of Agriculture of Western Polissya of the National Academy of Agrarian Sciences of Ukraine on crop rotation of winter wheat, corn, barley and winter rape. The object of the research was Albic Retisol (Arenic, Aric) (WRB, 2014) in a stationary trial. Before starting the research, soil pH_{KCl} was 4.3 and hydrolytic acidity (Hh) 2.80–2.97 cmol(+)·kg^{-1}. Liming fertilizer doses were determined on the basis of soil hydrolitic acidity (Hh) for dolomite flour: 0.5 Hh – $D_{d0.5}$ 2.230 t·ha^{-1}; 1 Hh – $D_{d1.0}$ 4,740 t·ha^{-1}; 1.5 Hh – $D_{d1,5}$ 6,700 t·ha^{-1} and lime flour: 1 Hh – $D_{l1.0}$ 4,940 t·ha^{-1}. Application of dolomite flour at a dose of $D_{d1.5}$ 6,700 t·ha^{-1} proved to be the most effective. It neutralised the acidity of the soil to the highest level pH_{KCl} (6.64) and maintained in this case pH_{KCl} 6.04 until the end of the 8-year of crop rotation. 3D modeling showed that the effectiveness of soil deacidification by dolomite flour increases with moderate simultaneous climate warming and humidification. Meanwhile, the simultaneous stronger increase of temperature and humidity weaken the neutralising effect of this liming fertilizer. The usage of dolomite and lime causes a gradual increase in Ca^{2+} soil content from 1.68 to 2.57 cmol(+)·kg^{-1} of soil similar to the dynamics of Mg^{2+} concentration (from 0.28 to 0.84 cmol(+)·kg^{-1} of soil). The usage of lime causes a maximum reduction content of soil Mg^{2+} (0.23 cmol(+)·kg^{-1} of soil) against the highest Ca^{2+} content. Doses of dolomite and lime had a significant effect on the Al^{3+} soil content. The concentration of Al^{3+} was highest in non-limed and fertilized areas in the final year of the crop rotation. The usage of dolomite rapidly reduced the content of exchangeable Al^{3+} from 2.48 and 2.67 cmol(+)·kg^{-1} of soil to 1.31 cmol(+)·kg^{-1} a 1.5 Hh dose. The average long-term crop-rotation productivity (in grain units) depended on the mineral fertilization and the type and doses of the liming fertilizers applied. Mineral fertilizers within the normal range $N_{112}P_{82}K_{105}$ without liming have contributed to the collection of 3.06 t·ha^{-1} grain units. The maximum crop yield was set on the option of applying 1.5 Hh dose of dolomite flour on the background of the average annual mineral fertilizer norms of $N_{112}P_{82}K_{105}$ – 5.33 t·ha^{-1} grain units. Lime flour proved to be less effective as it reduced the Mg^{2+} soil content, which is an important element for plants, and with a smaller impact on crop yield.

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1. Introduction

The soil cover of Ukraine Polissya is mainly slightly grained sod-podzolic soils (Albic Retisol (Arenic, Aric) according WRB 2014) with unfavorable physicochemical parameters and low humus and nutrient content (Venglinsky et al., 2014; Polovyi et al., 2018; Polovyy et al., 2021). These properties significantly limit crop productivity and profitability.

According to long-term state agroecological monitoring of agricultural lands (Venglinsky et al., 2014; Dolzhenchuk and Krupko, 2015), the area of acid soils in the Ukrainian Northwestern Polissya zone, which occupies the northern part of Rivne region, is almost 72.4% (173.6 thousand ha) of the total area (Table 1). Increasing the productivity of these soils requires, first of all, improving their physical and chemical properties by liming. This is a prerequisite for increasing humus and nutrient content (Higgins et al., 2012; Paradelo and Virto, 2015; Goulding, 2017; Polovyi et al., 2018; Szara et al., 2019; Pikuła and Rutkowska, 2020) and raising the intensity of microbiological activity. Measures are required to maintain soil health (Rousk et al., 2009; Malik, 2018). Liming is the most common and proven measure to radically improve the properties and fertility of acid soils (Lollato et al., 2013; Gibbons et al., 2014; Vašák et al., 2014; Chatzistathis et al., 2015).

Only 27.5% (65.9 thousand hectares – Table 1) of Polissya soils have a close to neutral, neutral and slightly alkaline reaction and do not require liming in Rivne region. These are, first of all, soils formed on forest areas and carbonate rocks. It should be noted that this distribution of soils by acidity is inherent in the whole Northwestern Polissya with slight variations. In Ukraine, most field studies focus on the effectiveness of fertilizers in neutralising the acidity of soils containing only Ca^{2+}. However, acidic soils of Northwestern Polissya tend to be low in Mg^{2+} (Polovyy, 2007; Dolzhenchuk and Krupko, 2015). Therefore it is important to study the effectiveness of liming fertilizers that contain magnesium like dolomite flour.

Our study aim was to investigate the effects of different doses of dolomite ($CaMg(CO_3)_2$) and lime flour ($CaCO_3$) on the transformation of Albic Retisol (Arenic, Aric) chemical properties and to compare their effectiveness with respect to soil pH_{KCl} and crop yields.

2. Materials and methods

In Ukraine, continuous agriecological monitoring of agricultural land is carried out by the Institute of Soil Protection of Ukraine and its branches in all regions of Ukraine (Dolzhenchuk and Krupko, 2015). We analyse the results of soil monitoring according to agrochemical analysis of the Rivne branch of the Institute of Soil Protection of Ukraine and compare the results of experiments in a stationary field trial of the Institute of Agriculture of Western Polissya National Academy of Agrarian Sciences of Ukraine (Fig. 1).

Table 1
Reaction of soils in the North-Western Polissya of Rivne region (average for 2006–2010 – Data from the Rivne branch of the Institute of Soil Protection of Ukraine

Reaction of soil	pH_{KCl}	Area. ha	%
Very strongly acidic and strongly acidic	<4.6	63.8	26.6
Medium acidic	4.6–5.0	63.1	26.3
Slightly acidic	5.1–5.5	46.7	19.5
Close to neutral	5.6–6.0	33.2	13.9
Neutral	6.1–7.0	28.5	11.9
Slightly alkaline	7.1–7.5	4.2	1.8
Sum	–	239.5	100

the boundary between Northwestern Polissya and Northwestern Forest-Steppe

Fig. 1. The Northwestern Polissya of Ukraine and localisation of Meteorological Station in Rivne (geographic coordinates: latitude – 48°14'50" N; longitude – 31°45'15" E; height above sea level – 151 m) (Ukraine. 2021. https://www.britannica.com/place/Ukraine)

In the stationary experiment, the object of research in 2011–2019 was the soil Albic Retisol (Arenic, Aric) (WRB, 2014), which is typical for Ukrainian Northwestern Polissya in the Rivne region. The alternation of crops in the model crop rotation was winter wheat, corn, spring barley, winter rape. Their yield was expressed in cereal units according to the appropriate coefficients: winter wheat – 1.0, grain corn and spring barley – 0.8, winter rape – 2.0. Mineral fertilizers for winter wheat were applied in a dose of $N_{120}P_{60}K_{90}$, for corn, $N_{120}P_{90}K_{120}$, for spring barley, $N_{90}P_{90}K_{90}$ and $N_{120}P_{90}K_{120}$ for winter rape. The average dose of fertilizer for crop rotation $N_{112}R_{82}K_{105}$ (as a background) was applied per hectare to the soil in the form of ammonium nitrate, simple superphosphate and potassium chloride. Dolomite flour was used for soil liming ($CaMg(CO_3)_2$ – 21% Ca, 12% Mg and lime flour ($CaCO_3$ – 60.1% Ca). The introduction of these frtilizers was carried out before the start of the experiment and with the option of no fertilization or liming. The dose of lime fertilizers was applied according to the formula D_a = 1.5 × Hh (t·ha^{-1}) for plowing at the initial level of pH_{KCl} 4.3 and hydrolityc acid (Hh) 2.80–2.97 cmol(+)·kg^{-1} of soil. Doses of liming fertilizers were determined according to soil hydrolitic acidity (Hh) for dolomite flour: 0.5 Hh – $D_{d0.5}$ 2.230 t·ha^{-1} (Ca_{478}+ Mg_{269} kg·ha^{-1}); 1.0 Hh – $D_{d1.0}$ 4.740 t·ha^{-1} (Ca_{1015} + Mg_{572} kg·ha^{-1}); 1.5 Hh – $D_{d1.5}$ 6.700 t·ha^{-1} (Ca_{1435} + Mg_{809} kg·ha^{-1}) and 1.0 Hh – $D_{l1.0}$ 4.940 t·ha^{-1} (Ca_{2998} kg·ha^{-1}) for lime flour.

Laboratory chemical analyses were performed according to standardised methods (Jackson et al., 1986; Thomas, 1996; State Standard, 2005; 2014; 2015a; 2015b): pH_{KCl} by potentiometric method; hydrolytic acidity by Kappen's method; exchangeable Ca^{2+} and Mg^{2+} using 1 M ammonium acetate buffer solution with pH 4.8 and analysed by an atomic absorption spectrometer; exchangeable Al^{3+} by Sokolov method (extraction with 1.0 M KCl (1:2.5) shaken for 1 h. The degree of base cations saturation (BS, %) was calculated as BS = (TEB – total exchangeable base/ CEC – cation exchange capacity) × 100%. where: TEB and CEC in cmol(+)·kg^{-1} of soil.

3. Results

Experimental results show that in areas without fertilizer, the pH_{KCl} of Albic Retisol (Arenic, Aric) from 2011 tended to decrease. This confirms the acidification of the soil from pH_{KCl} 4.30 to 4.10 during two crop rotation cycles until 2019 (Fig. 2).

Application of mineral fertilizers during 8 years at the average rate of 1 ha in the crop rotation area $N_{112}P_{82}K_{105}$ caused significant acidification of the soil from pH_{KCl} 4.39 to 4.00. This change in acidity confirms the threat of soil degredation and fertility loss as a result failing to lime. Many experiments have been conducted in Ukraine to study the effect of lime as a chemical soil deacidifier. However, scientists have done little research on dolomite flour. No analysis of efficiency of its various doses has been carried out. According to our results, half the dose of dolomite $D_{d0.5}$ 2.230 t·ha^{-1} (Ca_{478}+ Mg_{269} kg·ha^{-1}) neutralised the soil pH_{KCl} by 1.25 in the fifth year of crop rotation and by 0.49 before the end of rotation after 8 years. The dose of dolomite flour $D_{d1.0}$ 4.740 t·ha^{-1} (Ca_{1015} + Mg_{572} kg·ha^{-1}) was more effective. Correspondingly, in the fifth year of the research pH_{KCl}, reached 6.11 and 5.62 at the end of the rotation. However, application of dolomite flour at a dose of $D_{d1.5}$ 6.700 t·ha^{-1} (Ca_{1435}+ Mg_{809} kg·ha^{-1}) proved to be the most effective. The maximum value of pH_{KCl} (6.64) in the experiment was in the fourth year of rotation as well at the end of crop rotation (6.04). Lime flour at a dose of $D_{l1.0}$ 4.940 t·ha^{-1} (Ca_{2998} kg·ha^{-1}) had a significant positive soil acidity neutralisation effect. However, the effect of lime was slower and weaker than that of a similar dose of dolomite.

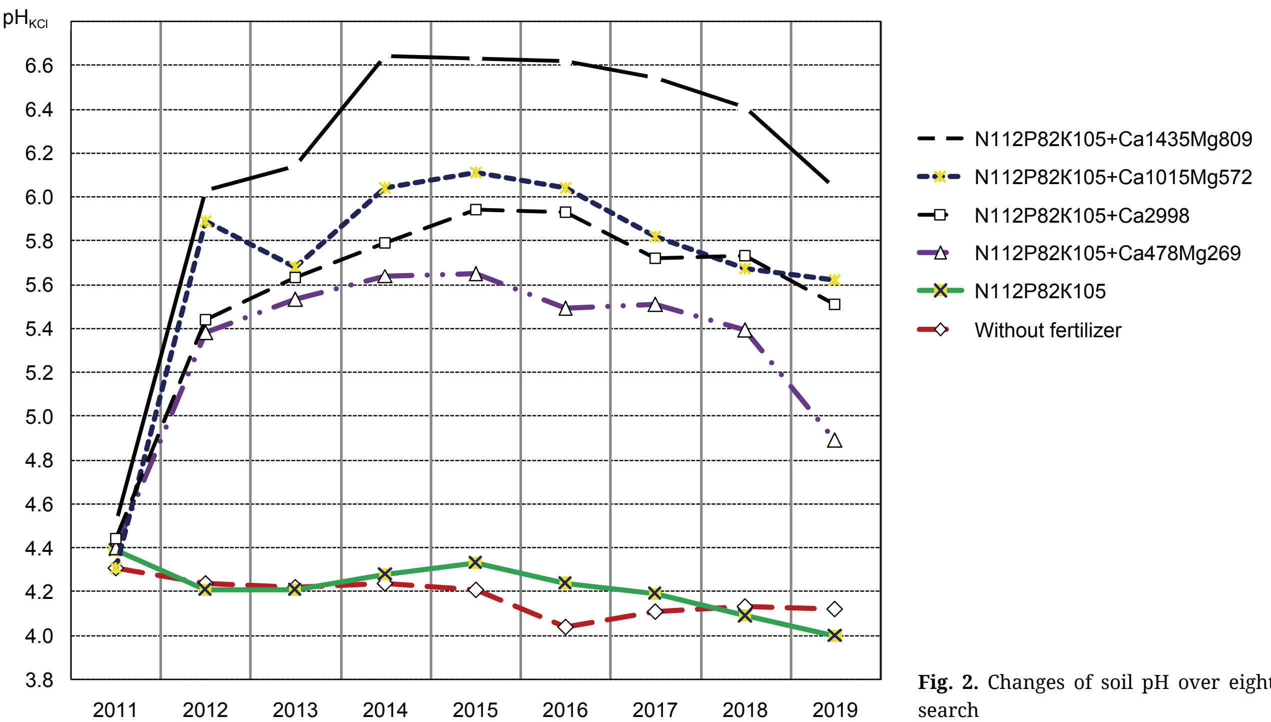

Fig. 2. Changes of soil pH over eight years of research

Our parallel monitoring of climatic indicators revealed interesting connections between temperature indicators, precipitation levels and actual acidity indicators at different doses of liming between 2011 and 2019 (Fig. 3). The average temperature trend for 8 years had inverse correlations with that of soil pH_{KCl} on variants with and without fertilizers but without liming (respectively r = –0.38 and –0.46).

However, with the introduction of dolomite flour in doses of $D_{d1.0}$ 4.740 t·ha^{-1}, $D_{d1.5}$ 6.700 t·ha^{-1}, the change in pH_{KCl} was clearly positively correlated with average temperature in the studied years. The closest connection was in the area where pure lime (r = 0.36) was introduced. The change in soil pH_{KCl} did not have a significant relationship with the amount of annual precipitation on the options without application of lime. However, already half of the dolomite dose caused a significant positive correlation of pH_{KCl} with the amount of annual precipitation (r = 0.45). The correlation was weaker in the rest of the limed areas though it was still positive. Soil without fertilizer or with mineral fertilizer but without liming reacted weakly or moderately as pH_{KCl} changed to fluctuations in the average year temperature and did not show a connection to the amount of precipitation. Instead, the application of lime in different doses reduced the acidity of the soil in direct proportion to the amount of precipitation and slightly lower than average year temperature.

3D-modeling of the interdependence dynamics between the soil pH_{KCl} and two climatic parameters allowed visualisation of their regression range (Fig. 4). The acidification of the soil with mineral fertilizers (Fig. 4 – A) is lower in dry years and during

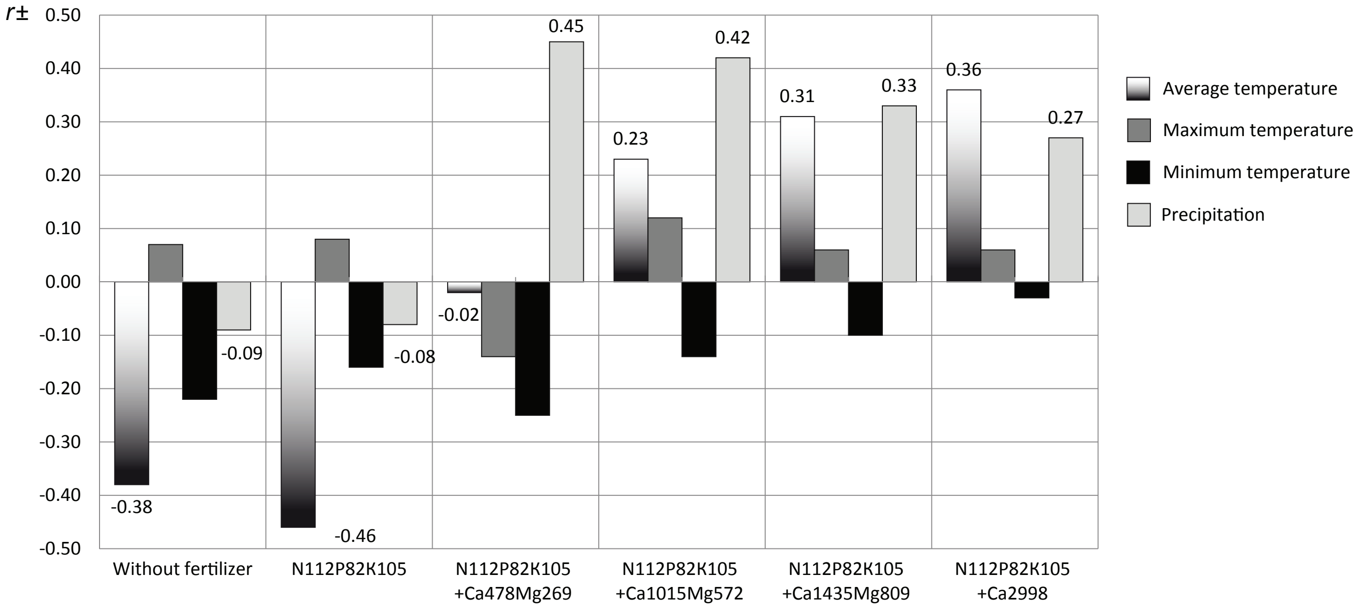

Fig. 3. Correlations of pH_{KCl} dynamics with average annual climatic indicators depending on soil fertilization and liming, $r\pm$

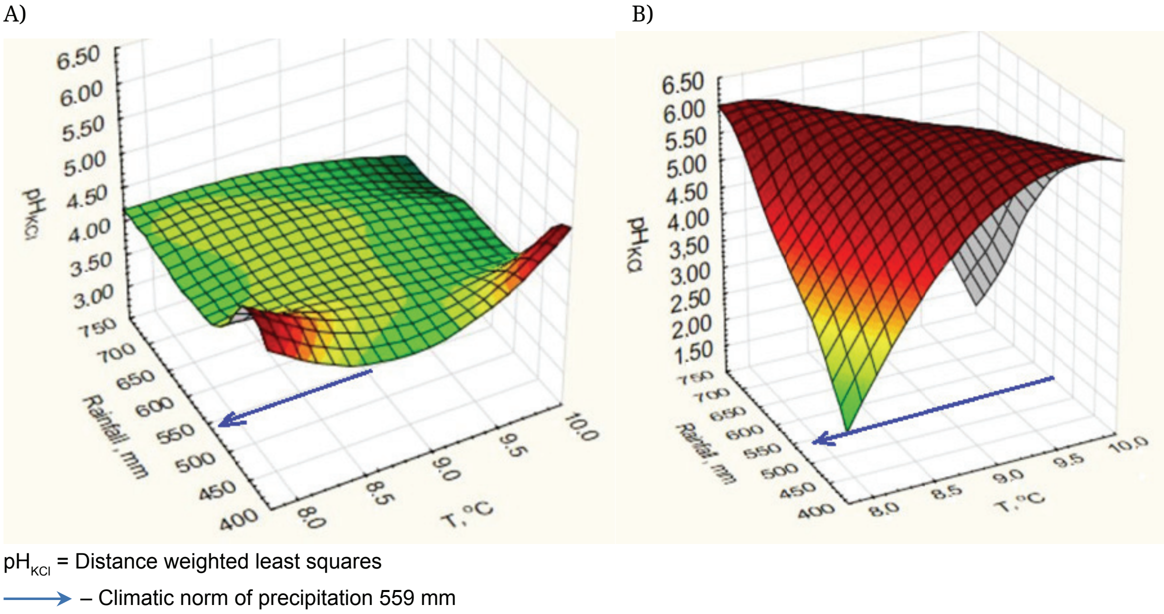

Fig. 4. Regression 3D-model of soil pH_{KCl} dynamics depending on average annual temperatures and precipitation on fertilized areas $N_{112}P_{82}K_{105}$ without liming (A) and with dose of dolomite 1 Hh ($D_{d1.0}$ 4.740 t·ha^{-1}) (B)

periods of elevated average annual temperatures. High rates of annual rainfall, especially with increasing temperature, increase the acidification of soil treated with only mineral fertilizers.

Against the background of dolomite dose 1 Hh with a minimum of precipitation, the neutralization of acidity is stronger the higher the heat source (Fig. 4 – B). At minimum temperature, soil acidity fell with increased precipitation. However, simultaneous increase of annual heat and moisture resources to the average per crop increased the pH_{KCl} rotation to the maximum. With further simultaneous growth in the maximum values of heat and moisture, the acidity of the soil still increases. We explain this by the negative correlation of these climatic resources – r = –0.50. Note that the construction of similar 3D models for smaller and larger doses of application of lime fertilizers showed a large similarity of pH_{KCl} regression planes from the average annual temperature and moisture content. This means that the maximum efficiency of lime fertilizers on soils is visible in the simultaneous warming and humidification of the climate in the Ukrainian Northwestern Polissya. In the 8 years of rotation, only 4 had precipitation higher than the climatic norm of 569 mm. However during all years of research, average annual temperature was significantly higher than the climatic norm of 7°C. As we noted, the correlation between climatic indicators was average but negative at r = –0.50.

We analysed the connections of climatic resources in the warm periods of the year (April-October) and found similar correlations. The closest was the negative relationship of pH_{KCl} with the average temperature in the warm months (r = –0.62) for purely mineral fertilization. We conclude that the lack of liming for Albic Retisol (Arenic, Aric) with pure mineral fertilization in the warming Ukrainian Polissia mesoclimate can cause significant soil acidification. Moreover, liming did not affect the relationship of pH_{KCl} with warming during the growing season. Instead, the amount of precipitation clearly affected the dynamics of pH_{KCl}; without liming, the effects was negative and the effect was only positive with all variants of liming. Thus with the increase of moisture supply, the efficiency of liming also increases significantly.

Ca^{2+} and Mg^{2+} from soil dolomite was converted into nutrients for field crops and soil microbiota. The content of calcium cations was the lowest in the soil without the introduction of lime fertilizer acidity reducers and especially for pure mineral fertilizers (Fig. 5). The application of dolomite and especially lime caused a gradual increase of Ca^{2+} in the soil sorption complex from 1.68 to 2.57 cmol(+)·kg^{-1} of soil. A similar dynamic on Mg^{2+} concentration (from 0.28 to 0.84 cmol(+)·kg^{-1} of soil) has been observed. However, the application of lime causes a maximum reduction of Mg^{2+} content in the soil sorption complex (0.23 cmol(+)·kg^{-1} of soil) against a background of highest Ca^{2+} content. This creates a very unfavorable imbalance in field crop nutrition.

The ratio of Ca^{2+} and Mg^{2+} becomes most favorable when used to neutralise the acidity of the soil dolomite flour at a dose of 1.5 (1.5 Hh) and it was equal to 3 (Fig. 6). However, there is a significant improvement with a half or a whole dose (0.5 and 1 Hh). The highest degree of soil base saturation occurred at 1 and 1.5 (1 and 1.5 Hh) dolomite flour doses at 63 and 72%.

Different doses of dolomite and lime had a significant effect on the content of exchangeable soil Al^{3+} in the final year of crop rotation (Fig. 7). The concentration of Al^{3+} was the highest at 2.48 and 2.67 cmol(+)·kg^{-1} of soil in non-limed and fertilized areas. The application of dolomite rapidly reduced the content of exchangeable soil Al^{3+} up to 1.31 cmol(+)·kg^{-1} of soil with 1.5 doses (1.5 Hh). There was a close direct correlation between the content of exchangeable soil Al^{3+} and hydrogen cations H^+ (r = 0.83).

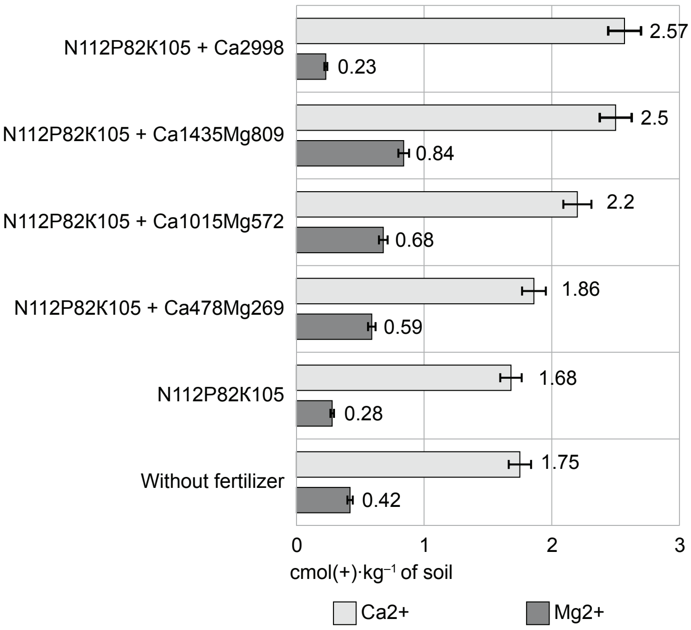

Fig. 5. Changes in the content of exchangeable Ca^{2+} and Mg^{2+} in the soil sorption complex under the influence of liming during eight years of research

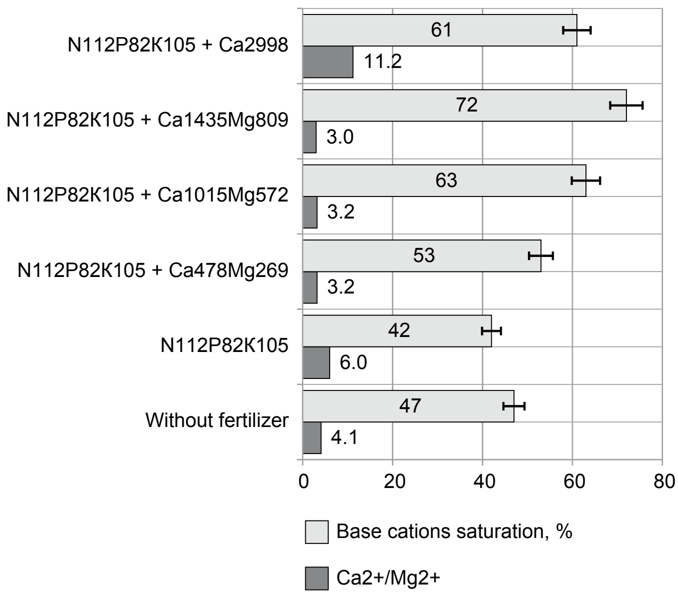

Fig. 6. Base soil saturation and ratio of Ca^{2+} to Mg^{2+} after eight years of fertilizer application and liming prior to crop rotation

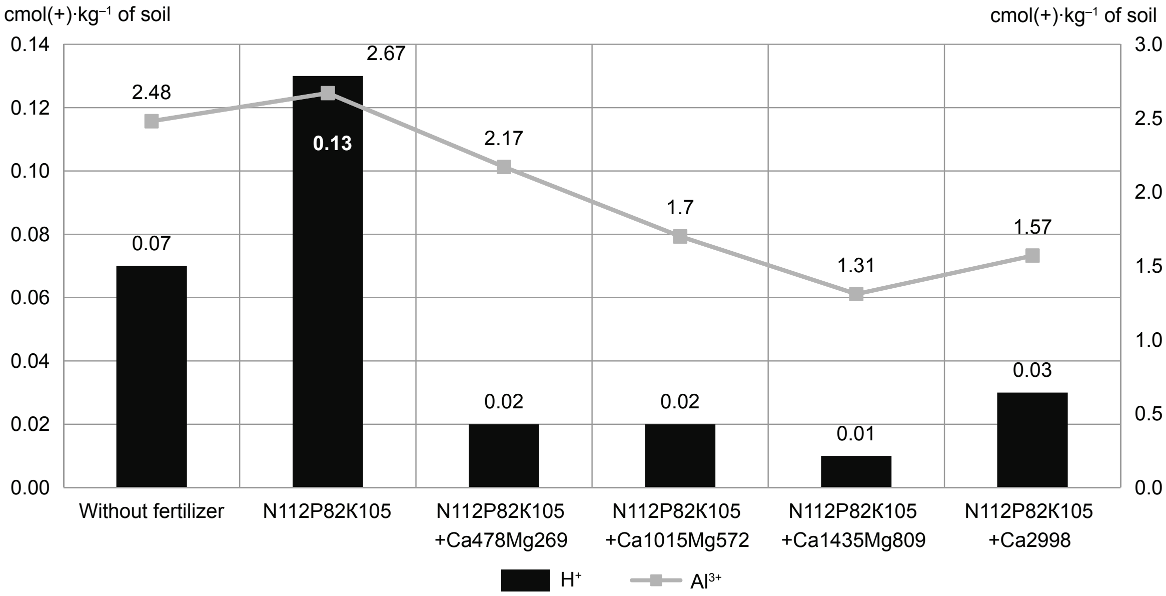

Fig. 7. Changes in the content of exchangeable soil Al^{3+} and H^{+} under fertilization and liming over eight years of research

Thus the eight-year dynamics of acidity and transformation of exchange cation composition in the soil sorption complex was strongly dependent on fertilization, doses and type of lime fertilizers. The acidic properties and proportion of ions in the studied Albic Retisol (Arenic, Aric) change significantly, which is the change that affects soil fertility.

All crop yields during the eight-year rotation are listed with a unified grain unit indicator. Average long-term crop-rotation productivity depended on mineral fertilizers, dosing and type of lime fertilizers. In the variant without fertilization, 2.07 t ha^{-1} grain units were obtained (Fig. 8).

Only mineral fertilizers in the norms $N_{112}P_{82}K_{105}$ in the form of ammonium nitrate, simple superphosphate and potassium chloride have contributed to the collection of 3.06 t·ha^{-1} of grain units. However already half of the estimated dose of dolomite flour (0.5 Hh) increased the crop rotation productivity by 0.96 tons of grain units per hectare. The maximum crop yield was achieved with the application of a 1.5 dose (1.5 Hh) of dolomite flour (5.33 t·ha^{-1} of grain units) with a background of average mineral fertilizer annual norm of $N_{112}P_{82}K_{105}$.

Pearson's correlation calculations showed that average eight-year crop rotation productivity depended very closely on

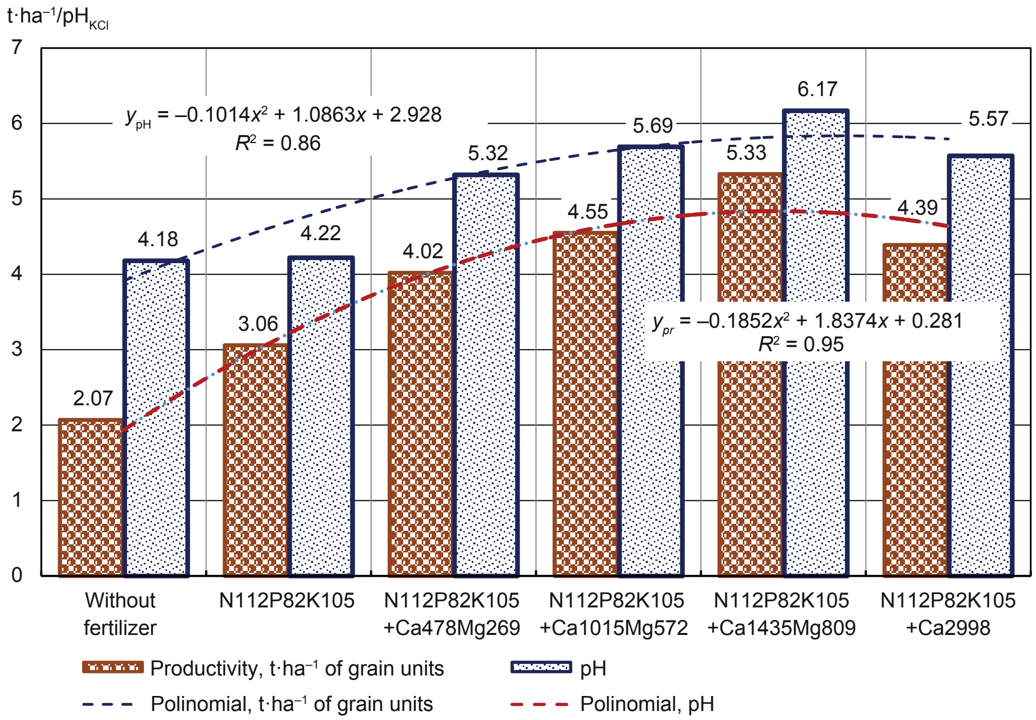

Fig. 8. Dependence of crop rotation productivity on changing soil pH under the influence of fertilization and liming between 2011 and 2019

the 8-year average pH_{KCl} – r = 0.97, and was also closely correlated with the pH_{KCl} in the last year of rotation at r = 0.94. A mathematical polynomial model of the spatial dynamics of pH_{KCl}, which depends on fertilizer and liming, with a high approximation index (R^2 = 0.86) describes this revealed pattern. A similar model with an even higher approximation index (R^2 = 0.95) describes the relationship between crop rotation productivity over 8 years with rates of Albic Retisol (Arenic, Aric) fertilization and liming.

4. Discussion

According to many authors of different origin, excessive soil acidity depends on fertilizer application (Mahler et al., 1985; Schroder et al., 2011; Vašák et al., 2014) or prolonged absence of liming in crop rotation. The reaction of the soil varies with the total moisture during the year (Slessarev et al., 2016; Ghimire et al., 2017). Physical and chemical properties are significantly impaired by the presence of aluminum cations (Godsey et al., 2007; Brown et al., 2008), manganese and copper (Chatzistathis et al., 2015). Increasing acidity changes soil composition (Rousk et al., 2010) and reduces arable-layer positive microbiome activity (Malik et al., 2018) and the fertility of soils (Barak et al., 1997; Crozier and Hardy, 2017; Pikuła and Rutkowska, 2020). Agricultural techniques like soil liming (Gibbons et al., 2014; Crozier and Hardy, 2017) and balanced organic and mineral fertilizers (Orzech and Załuski, 2020) allow to neutralisation of soil acidity to the optimal level for plant growth. Productivity of the majority of crops is greatly increased by neutralising acidic soils (Higgins et al., 2012; Lollato et al., 2013). However, managers use much less lime than needed even in the UK. Many arable and meadow soils have a pH lower than optimal (Goulding, 2017).

Studies (Polovyi et al., 2018) showed that there was a differentiation of chemical parameters and soil productivity depending on the long-term action of different lime doses and fertilizer application at different rates. Changes in soil agrochemical parameters were revealed under the influence of the confirmed climate aridisation of Western Ukraine (Polovyy et al., 2021). The studies presented in this article have shown that Albic Retisol (Arenic, Aric) soil in the Ukrainian Polissia responds very well to the application of lime fertilizers and is quickly acidified by use of purely mineral fertilizers. The application of dolomite flour at doses of 1.0 and 1.5 Hh and lime flour at a dose of 1.0 Hh before the start of rotation strongly neutralised soil pH_{KCl}. The effectiveness of these acidity-reducer doses showed a positive relationship with increases in average annual temperature and rainfall over a period of 8 years. 3D-models of the dependences of soil pH_{KCl} dynamics and two climatic indicators visualised lower soil acidification regularity with mineral fertilizers in dry years and elevated average annual temperatures. The increasing the rate of annual precipitation, especially with increasing temperature, increases soil acidification in the absence of liming. With the introduction of a 1.0 Hh dose of dolomite in minimum precipitation, the neutralization of acidity is stronger the warmer the year. In cold years, with more rainfall, soil acidity is also reduce though the simultaneous increase of annual heat and moisture to the average for 8 years of crop rotation increased the pH_{KCl} to a maximum. With excessive simultaneous temperature and moisture increase, the neutralising effect of the studied doses of acidity reducers is weakened in Ukrainian Northwestern Polissya. 3D models for other doses of acidity reducers showed the great similarity of pH_{KCl} regression planes from the average annual temperature and amount of moisture. This means that the efficiency of liming fertilizer on soils is highest for synchronous warming and humidification of the Ukrainian Polissia climate though not beyond excessive levels. The established scientific results are new for the conditions of Ukrainian Northwestern Polissya and indicate the need to correct the practice of liming acid soils to achieve optimal pH_{KCl}, reproduction of fertility Albic Retisol (Arenic, Aric) and favorable productivity of arable land with further climate warming transformation.

Ukrainian Northwestern Polissya soils have low exchangeable Ca^{2+} and magnesium cation content. This negatively affects not only the acidity of soils but also crop nutrition (Table 2). This issue has already been studied by Brodowska and Kaczor (2005), who demonstrated that liming the arable layer of sandy soil significantly improves the Ca^{2+} and Mg^{2+} supply for spring wheat and rapeseed. Nazarkiewicz and Kaniuczak (2012a) showed that the combination of liming and mineral fertilizer improves the content of available Mg^{2+} in Haplic Luvisols. In a study of Albic Retisol (Arenic, Aric), the weighted average content of Ca^{2+} was 7.4 (average security) and Mg^{2+} 0.4 cmol(+)·kg^{-1} of soil (very low security).

The share with very low or low supply of exchangeable cations of Ca^{2+} and Mg^{2+} is 50.7% and 91.5% of the surveyed Polissya Rivne region soil. In our 8-year experiment, when applying $N_{112}P_{82}K_{105}$ per 1 ha, we found on average the lowest content of exchangeable Ca^{2+} – 1.68 and in the variant without fertilizer 1.75 cmol(+)·kg^{-1} of soil. Application 0.5; 1.0 and 1.5 Hh doses of dolomite flour caused an increase in content by 10.7%; 40.0% and 49.0% compared with only mineral fertilizers. At the same time, in the variants without fertilizers and with the application

Table 2
Groups of abundance in exchangeable Ca^{2+} and Mg^{2+} of agricultural soils in the Rivne Polessya region (result of continuous agroecological monitoring of the area of 260300 ha for 2001–2006)

Cation	soil abundance groups, %					
	very low	low	medium	elevated	elevated	very high
Ca^{2+}	21.8	28.9	24,8	13.0	6.6	4.9
Mg^{2+}	74.3	17.2	8.5	–	–	–

Data from the Rivne branch of the Institute of Soil Protection of Ukraine (Rivne, Ukraine) of $N_{112}P_{82}K_{105}$ crop rotation on average per 1 ha, Mg^{2+} content was 0.42 and 0.28 cmol(+)·kg^{-1} of soil respectively. With the introduction of 0.5 Hh CaMg $(CO_3)_2$, it increased to 0.59 cmol(+)·kg^{-1} of soil. Increasing the dose of dolomite flour to 1.0 and 1.5 Hh doses contributed to the growth of exchangeable Mg^{2+} accordingly to 0.68 and 0.84 cmol(+)·kg–1 of soil. Limestone flour ($CaCO_3$) neutralized the acidity and at the same time reduced exchangeable Mg^{2+} soil content by almost double that of control. This is due to a significant increase in assimilation as crop yields increased. The application of lime after 8 years reduced the content of exchangeable Mg^{2+} in the soil by 3 times compared to the use of dolomite flour. This indicates a significant advantage of the application of calcium-Mg^{2+} flour, compared to pure lime in soils with low Mg^{2+} content. The optimal ratio of Ca^{2+} to Mg^{2+} is important for soil fertility in Ukrainian Northwestern Polissya like in other conditions (Brodowska and Kaczor, 2005; Jaskulska et al., 2014; Crozier and Hardy, 2017). Results showed that in the variants without fertilization and with the introduction of an average of 1 ha of crop rotation $N_{112}P_{82}K_{105}$, the ratio between the cations of Ca^{2+} and Mg^{2+} in the soil sorption complex was 4.1 : 1 and 6.0 : 1 respectively, which for the application of dolomite flour Ca^{2+} : Mg^{2+} narrowed to 3.2 : 1 and 3.0 : 1. The ratio was weakly dependent on the dose of dolomite, as Mg^{2+} assimilation increased with crop yields together with the also increasing dolomite dose. The introduction of calcium carbonate caused a significant increase of Ca^{2+} : Mg^{2+} value to 11.2 : 1. This may cause a decrease in yields due to Mg^{2+} soil deficiency.

Al^{3+} has a largely negative effect on the metabolic complex of soil (Brown et al., 2008; Godsey et al., 2007; Nazarkiewicz and Kaniuczak, 2012b). Aluminum phosphates that are rare for plants to form were created (Szara et al., 2019). The application of dolomite flour at a dose of 1.5 Hh reduced the content of exchangeable Al^{3+} from 2.48 and 2.67 cmol(+)·kg^{-1} of soil in non fertilized and limed areas to 1.31 cmol(+)·kg^{-1} of soil in tested soils.

Optimisation of acidic Albic Retisol (Arenic, Aric) chemical properties helps to increase soil fertility in Ukrainian Northwestern Polissya. Was received 5.33 t·ha^{-1} of grain units on average over 8 years with the introduction of 6.70 t·ha^{-1} (1.5 Hh) of dolomite flour. Application of 4.7 t·ha^{-1} (1.0 Hh) of dolomite flour provided 4.55 t·ha^{-1} of grain units. Replacement of dolomite with pure limestone flour provided only 4.39 tons of grain units. Therefore the application of dolomite flour on acid soils is an effective agronomic technique for increasing soil fertility and crop yields. Many researchers have proven this experimentally under different conditions (Schroder et al., 2011; Jaskulska et al., 2014; Paradelo et al., 2015; Crozier and Hardy, 2017; Goulding, 2017; Polovyi et al., 2018).

5. Conclusion

The very strong acidification of Albic Retisol (Arenic, Aric) soils in the North-Western Polissya of Ukraine may be decreased if they are limed with dolomite flour in doses of 1–1.5 Hh ($D_{d1\cdot0}$ 4,740 t·ha^{-1}, $D_{d1,5}$ 6,700 t·ha^{-1}). Fertilization of this kind reduced soil acidity to almost neutral after the second year of crop rotation with 1.5 Hh doses and in the fifth year with 1.0 Hh.

With the application of liming fertilizer in 1.0 and 1.5 Hh doses, the change in pH_{KCl} was weakly but positively correlated with the average temperature in the studied years, and also moderately but positively correlated with the amount of annual precipitation. Effectiveness of soil deacidification by dolomite flour increases with moderate simultaneous climate warming and humidification. Meanwhile, the simultaneous greater increase of temperature and humidity weaken the neutralizing effect of this liming fertilizer.

Both fertilizers used for liming caused increase pH_{KCl} value, base saturation and at the same time decreased the soil content of exchangeable Al^{3+}. However, use of lime flour resulted in a decrease content of exchangeable magnesium in the soil and an increase of Ca:Mg value, creating a very unfavorable cationic imbalance in the mineral nutrition of field crops.

The statistical analysis of results showed a high positive correlation between soil liming doses, an increase of the pH value and arable crop yields. The application of the highest dose of dolomite flour (1.5 Hh) caused an increase of pH_{KCl} to 6.17 and the yield of arable crops in the 8-year crop rotation to 5.33 t·ha^{-1} grain units compared to 3.06 t·ha^{-1} grain units obtained on the area without liming.

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