Agroecological evaluation of profiles with eroded arable and virgin soil in the pot experiment with pea at the northern part of steppe zone of Ukraine

Mykola Kharytonov, Valentina Pashova, Mariia Bagorka, Oleksandr Mytsyk, Yuriy Tkalich, Svitlana Lemishko

Dnipro State Agrarian and Economic University, Faculty of Agronomy, Dnipro, Serhii Yefremov str., 25, 49009, Ukraine

*Corresponding author, e-mail: kharytonov.m.m@dsau.dp.ua

Received: 02.03.2024 / Accepted: 29.07.2024

Abstract. The effective fertility of the humus horizon of mildly washed soil in terms of the productivity of aboveground mass of peas is the highest among all humus genetic horizons. The fertility of the upper horizon with very prominent humus accumulation (Hp), lower transition horizon, with little humus (Phc), and underlying parent material (Pc) horizons is 20% lower than the upper horizon with very prominent humus accumulation (H) horizon. The accumulation of macroelements by peas on the soils of virgin slopes is less than on the soils of arable slopes - by 18% for nitrogen, 36% for phosphorus, and 15% for potassium. The maximum accumulation of nitrogen, phosphorus and potassium by pea was on mildly sloped soil from the 0-10 and 10-20 cm layer comparative to moderately sloped one. The absorption of trace elements by pea depends on environmental conditions and can be divided into three groups: elements of high concentration - Fe, Mn, Zn, medium - Cu, Ni and Pb, and low - Co and Cd. An established pattern: the content of trace elements in plants grown in deeper layers decreases.

Keywords: soil profile, pea, productivity, element accumulation

1. Introduction

The water soil erosion leads to hillslopes and midslopes degradation and depositing it on the footslopes (Moges and Holden, 2008; Hladky et al, 2016; Amede et al, 2023). The use of cover crops (CCs) in commodity crop production systems can improve soil organic matter by decomposing residues, thereby increasing soil carbon and nitrogen concentrations, stabilizing soil aggregates, increasing porosity, and reducing bulk density (Munoz et al., 2014; Blanco-Canqui and Ruis, 2020). It was reported that legume CCs increased corn yield by 37% compared to no CCs (Miguez and Bollero, 2005). A number of authors noted that the effect of CCs on crop yields in a terrace-tiled field was variable because of spatial and temporal landscape variability (Harmoney et al., 2001; Guretzky et al., 2004). That is why, understanding the topographical effects of nutrient cycling can contribute to a better implementation of improved management practices including CCs, nutrient management, and terraces (Kaur et al., 2023). Nitrogen has been the limiting nutrient in landscapes with pronounced topography due to continuous cropping with application of limited external inputs (Kharytonov and Velichko, 2017; Magrini et al., 2016). That is why it is necessary to improve soil nutrient availability using legumes in crop rotation. Grain legumes such as field pea are known high variability of yield and nitrogen fixation between seasons and the yearly spatial variability within a field (Hauggaard-Nielsen et al., 2010). The reintroduction of grain legume crops (for feed and/ or food) deserves particular attention because of their complementarity in N exploitation, reduction in the use of fertilizers, and increased yield and quality traits of the final products (Fan et al., 2006; Stagnari et al., 2017; Mawois et al., 2019; Mesfin et al., 2023). Understanding the expression of adaptive potential in landscape settings is essential for making optimal landscape-specific fertilizer management decisions and long-term nutrient management strategies (Desta et al., 2023). The uptake of macro- and microelements by plants varied significantly within the landscape because both physical and chemical soil properties are responsible for the difference in nutrient status (Kalpana et al., 2015).

The main objective of this case study was to conduct an agroecological assessment of profiles with eroded arable and virgin soil in a pot experiment with pea at the northern part of steppe zone of Ukraine.

2. Materials and methods

Two neighboring landscapes with arable and virgin soils were selected for field observations. These sites coordinates are: 48^{o}30’ E lat. and 35^{o}15’N long. They are located far away from the Dnipro city (25-30km) enough to avoid industrial pollution effect. The experiments reported here compare soils from two types of landscapes: mildly sloped soils (1-3%) with mild erosion (E1, =10 cm topsoil loss), and moderately sloped soils (5-7%) with moderate erosion (E2, up to 30 cm topsoil loss). Generally, duplicate determinations were made and averaged. The depth increments were assigned to general soil horizons. The depth increments were assigned to general soil horizons, according to the Ukrainian soil taxonomy system (Kharytonov et al., 2004):

H - upper horizon with very prominent humus accumulation

Hp - upper transition horizon, with considerable humus

Phc - lower transition horizon, with little humus

Pc – underlying parent material

The H, Hp, Phc and Pc horizons encompassed depths of depths of 0-30, 30-50, 50-70, 70-100 cm for E1, and depths of 0-30, 30-50, 50-100 cm for E2 (with the H horizon absent entirely due to erosion). Ph and P horizons were marked as Phc and Pc because of carbonates presence. Soil samples were taken every 10 cm to a depth of 100 cm. The pot experiments with pea were managed during four years. The pot volume was 5 kg, repetition - 3. The nitrogen and phosphorus concentration in plant samples was estimated using Kjeldahl method. Total P concentrations of the applied residues were determined by sulfuric acid digestion (Thomas et al., 1967). Potassium and trace elements were determined with flame atomic absorption spectrophotometry. All elements content was presented in dry mass. Statistical analysis of each experiment was performed on Excel (2000), using the analysis package add-in.

3. Results and Discussion

The data on the influence of layer fertility of arable soils on the bioproductivity of pea are shown in Fig. 1 and 2. On mildly sloped soil (profile 0-10 cm), the average pea yield over 4 years was 9.6 g/pot and decreased with depth by 18%. On moderately sloped soil, similar data were 8.77 g/pot (productivity) and 14% (decrease in productivity). The results of determining the influence of layer fertility of virgin soils on the bioproductivity of peas are shown in Fig. 3 and 4. The maximum productivity of pea grown on the eroded soils of the virgin slope was 19% higher in mildly sloped soil than moderately sloped one.

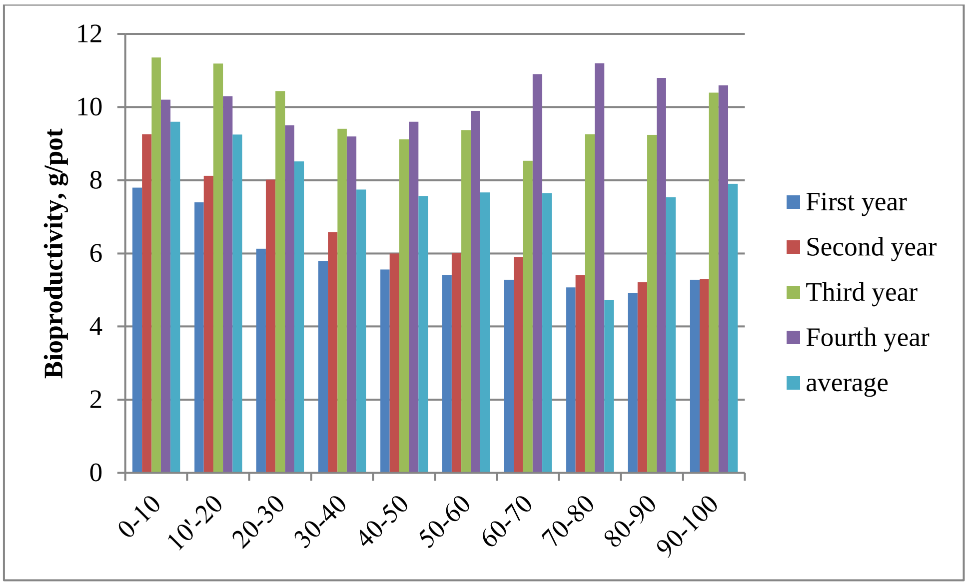

Fig.1. The dependence of the pea productivity on the depth of mildly sloped soil (arable land)

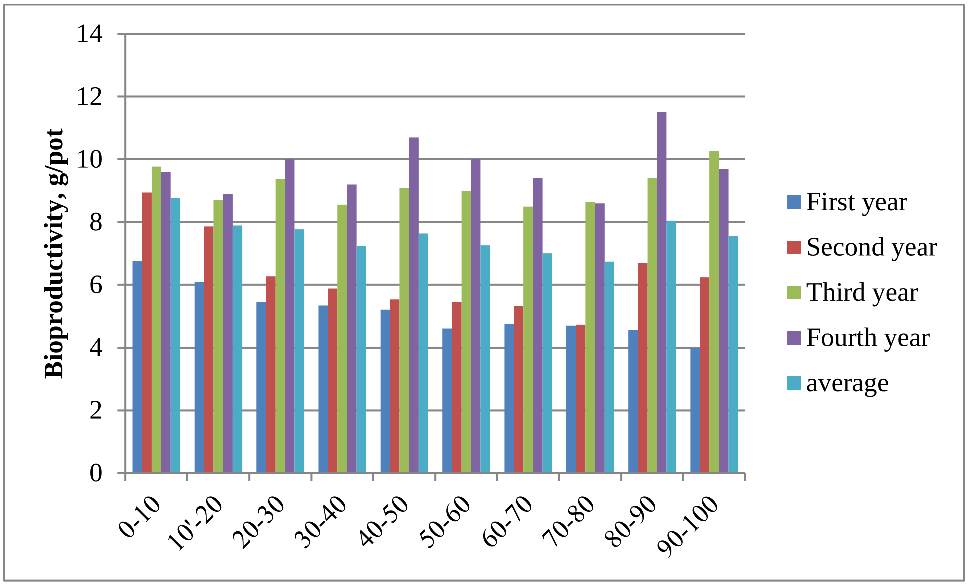

Fig. 2. The dependence of the pea productivity on the depth of moderately sloped soil (arable land)

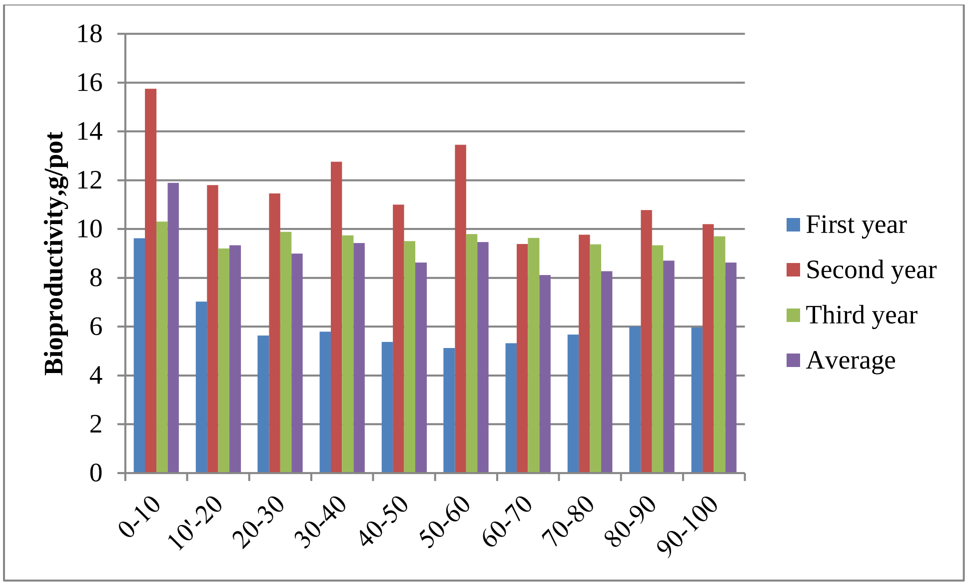

Fig. 3. The dependence of the pea productivity on the depth of the mildly sloped soil, (virgin land)

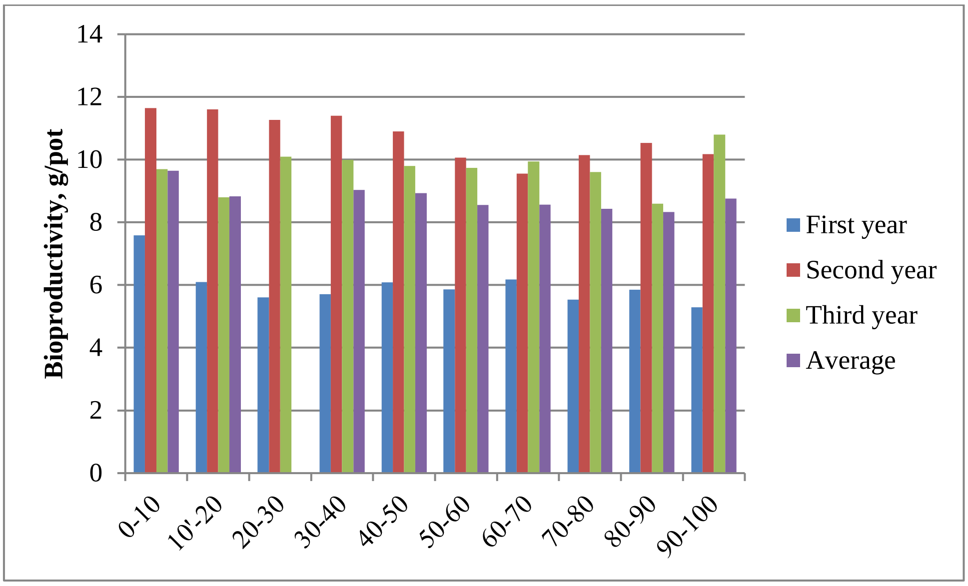

Fig. 4. The dependence of the pea productivity on the depth of the moderately sloped soil (virgin land)

Layer-by-layer records of pea bioproductivity on arable land were randomized in such a way as to reflect the fertility of individual genetic horizons of washed soils (Fig. 5 and 6).

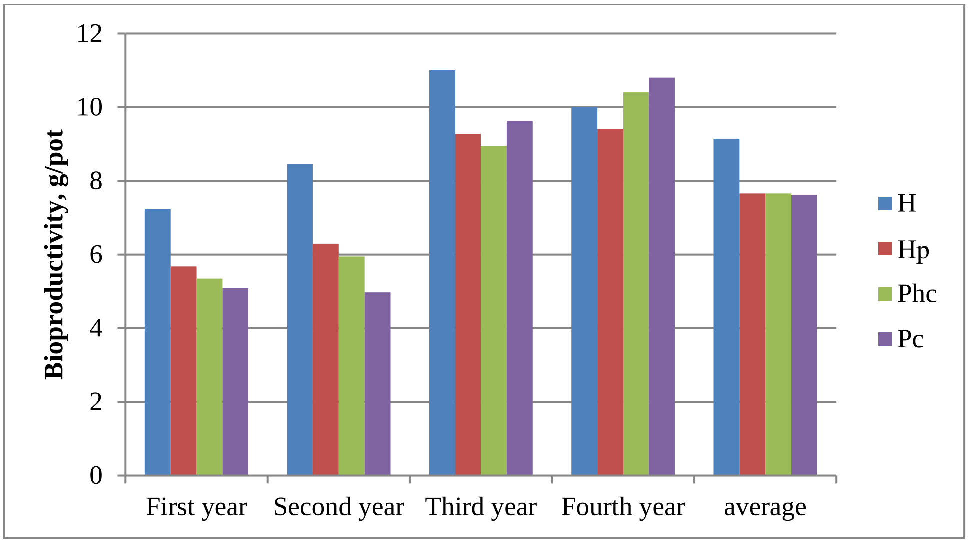

Fig.5. Productivity of pea on separate genetic horizons of mildly sloped soil (arable land)

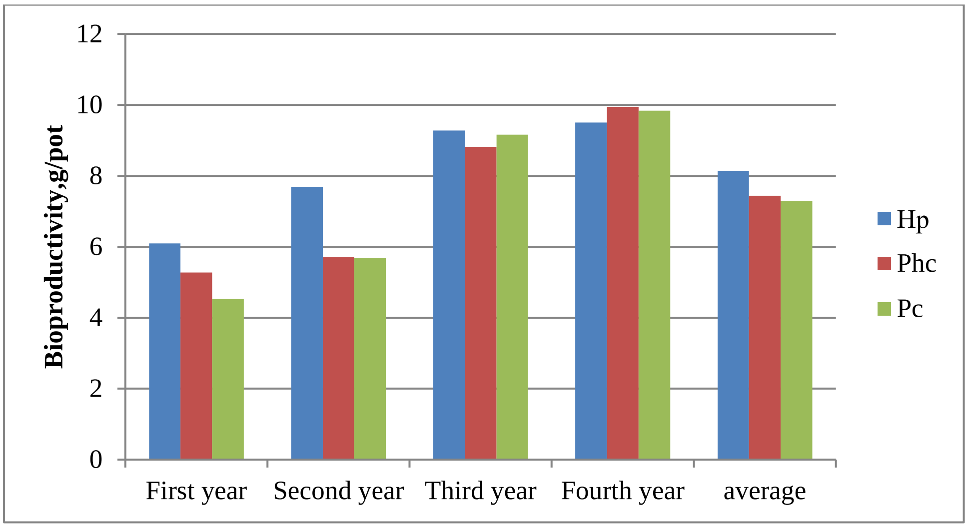

Fig.6. Productivity of pea on separate genetic horizons of moderately sloped soil (arable land)

Over the years, biological effective fertility, expressed by the productivity of pea, increases on all genetic horizons. This is especially evident in the P_c horizon (2.1-1.6 times). This can be explained by the faster transition of its potential fertility to effective as a result of soil phytomelioration at the vessels. Subsoil, deeper layers of soil brought to the surface retain reduced fertility in the first two years. In further use, the productivity of peas grown on soil at a depth of 80-90, 90-100 cm increased significantly. This can be explained by the ability of the pea root system to mobilize and use scarcely available reserves of soil nutrients. Layer-by-layer records of productivity of peas grown on two types of eroded virgin soils were randomized in such a way to reflect the fertility of individual genetic horizons of washed soils (Fig. 7 and 8).

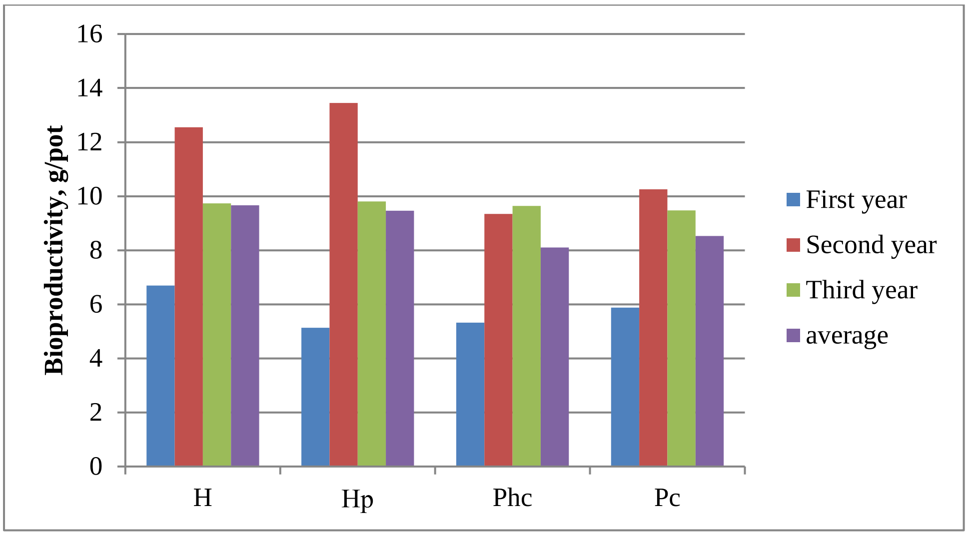

Fig.7. Productivity of peas on separate genetic horizons of mildly sloped soil (virgin land)

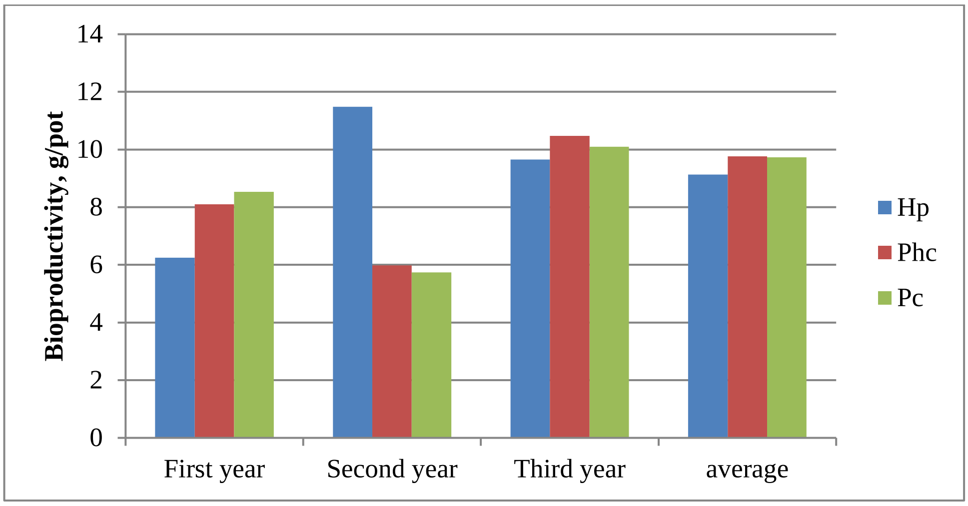

Fig.8. Productivity of peas on separate genetic horizons of moderately sloped soil (virgin land)

Considering the effective fertility of the genetic horizons determined by the productivity of pea, it should be noted that in all cases the humus horizon Hp was the most fertile (9.66 g/pot). The second transition horizon (Phc) and parent rock (Pc), located in different ecological conditions, differed slightly in terms of pea productivity (7.88 - 8.53 g/pot). The accumulation of macroelements by pea varies depending on the ecological conditions of the two compared landscapes (Fig. 9-14).

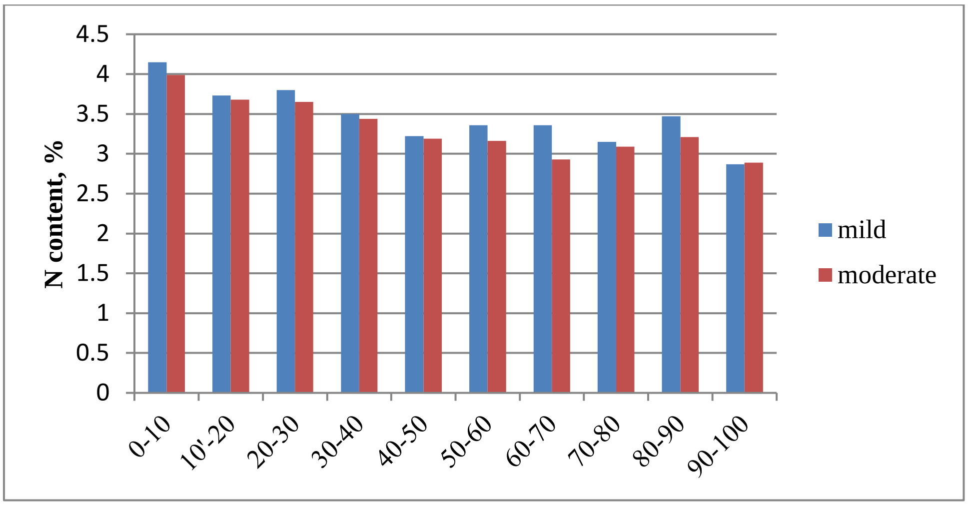

Fig.9. N content in the pea biomass (arable land), %

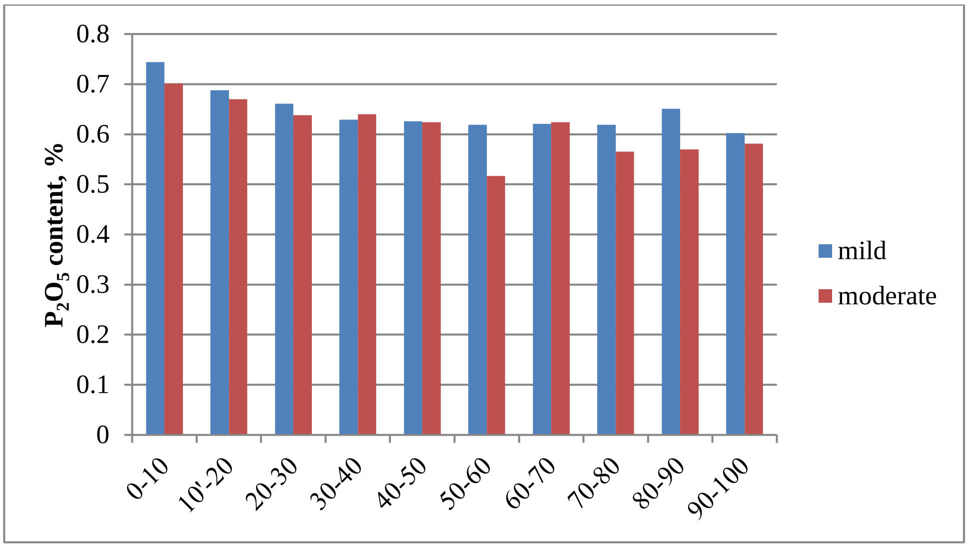

Fig. 10. P_2O_5 content in the pea biomass (arable land), %

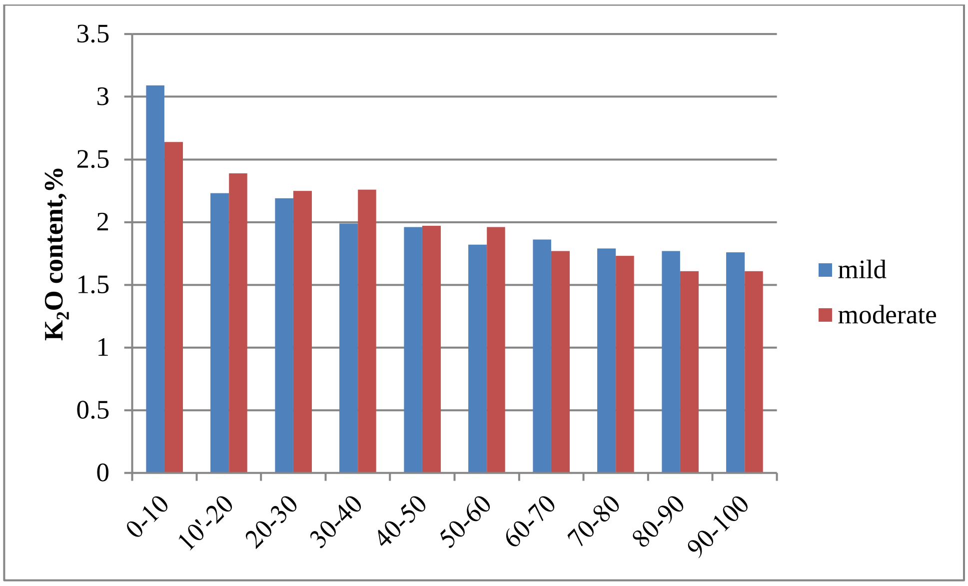

Fig. 11. K_2O content in the pea biomass (arable land), %

Absorption of nutrients by pea in deeper horizons is less than in the arable layer of 0-10 cm. The highest accumulation of nitrogen, phosphorus and potassium potassium occurs in the biomass of plants on infertile arable soils.

It was established that the maximum nitrogen content in the topsoil of virgin slope was 3.50% on the slope with mildly sloped soil, 3.17% on the slope with moderately sloped soil, phosphorus 0.475% and 0.492% and potassium 2.63% and 2.04%, respectively (Fig. 12-14).

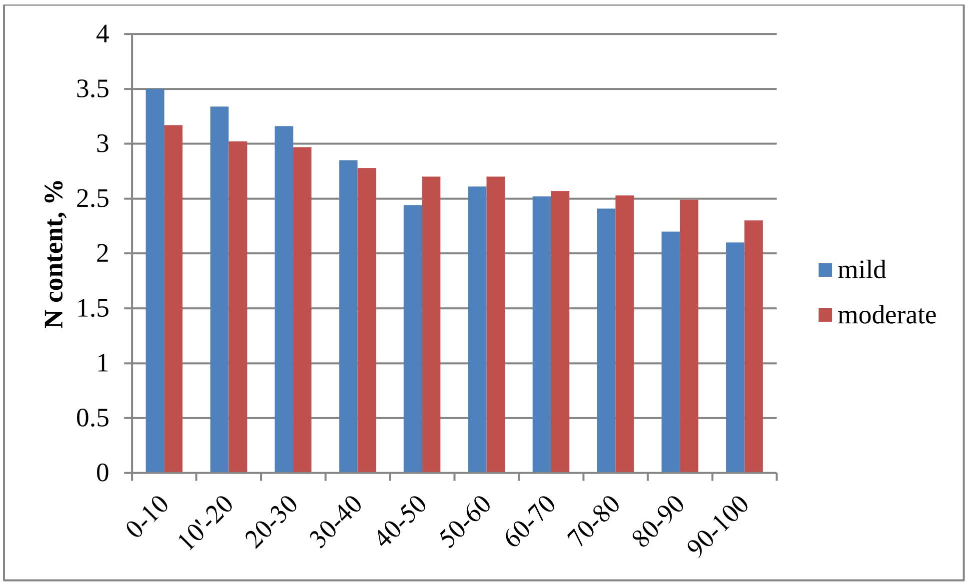

Fig. 12.N content in the pea biomass (virgin land), %

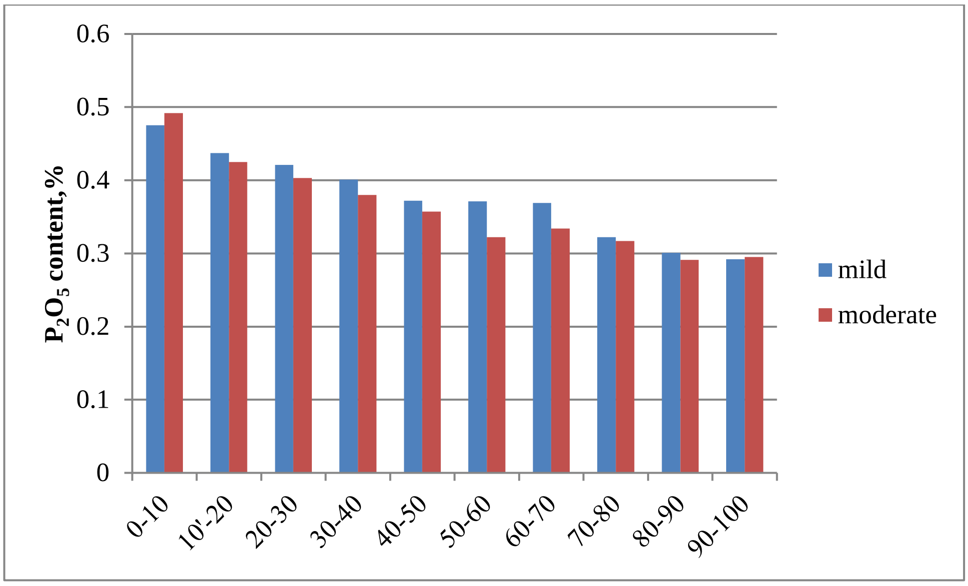

Fig. 13. P_2O_5 content in the pea biomass (virgin land), %

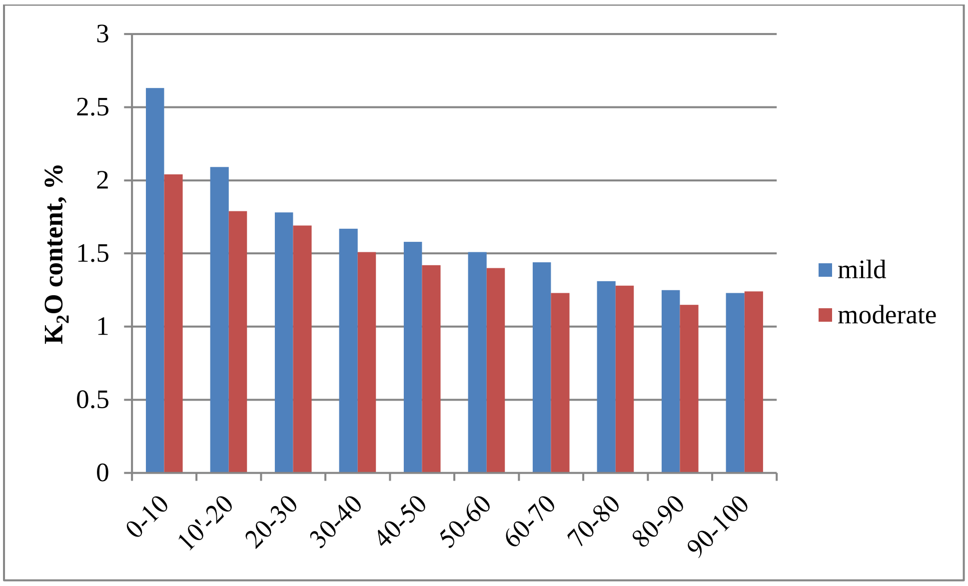

Fig.14. K_2O content in the pea biomass (virgin land), %

The nitrogen, phosphorus and potassium content in pea biomass obtained on virgin soils are significantly lower than on the horizons of arable slopes.

Peas on arable mildly sloped soil took up 13-15% more nutrients than on moderately sloped soil. The ratio of N : P_2O_5 : K_2O was 1 : 0.17 : 0.72. At the same time, it was noted that the indicators of the soil on the virgin land slopes were significantly lower than on the arable land slopes (Table. 1). The maximum uptake of nitrogen, phosphorus and potassium by peas along the profile was 231.8 mg/pot, 32.8 and 143.9 mg/pot in the mildly sloped soil, decreasing by 8, 4, 14 mg/pot, respectively, on the moderately sloped soil. It should be noted that the uptake of the main macronutrients by peas was higher in plants on arable land slopes: nitrogen - by 15%, phosphorus - 32%, and potassium - 14%. This indicates the soil condition including microbiological activity changes, and the mobilization of nutrients occurs that under the impact of the anthropogenic factor.

Thus, the consumption of nutrients per plant on the arable mildly sloped soil is nitrogen - 27.95 mg, phosphorus - 5.1 mg, potassium - 16.7 mg, while in the virgin soil: nitrogen - 23.18 , phosphorus 3.28 and potassium - 14.3 mg.

Thus, despite on the significant potential fertility of virgin slope soils, consumption of macronutrients by peas is 18% less for nitrogen, 36% for phosphorus, and 15% for potassium than on soils of arable slopes. This indicates a more effective use of macronutrients in virgin land conditions due to changes in water-physical properties.

Table 1. The uptake of macroelements with pea plants in arable and virgin slope soils, mg/pot

Slop soil	**Depth, cm**	**Arable slope soil**			**Virgin slope soil**		
		N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Mild	0-10	401.2	71.6	289.7	393.5	54.2	295.0
	10-20	334.8	63.4	209.5	286.6	38.5	188.8
	20-30	392.0	60.0	199.2	248.7	35.3	148.4
	30-40	264.7	48.8	163.0	226.3	34.1	141.8
	40-50	235.5	47.3	157.8	227.7	30.4	125.2
	50-60	232.9	44.3	114.6	205.3	31.6	126.0
	60-70	221.7	42.3	132.8	195.9	29.7	110.1
	70-80	213.5	44.5	139.8	186.4	26.0	103.6
	80-90	223.0	45.2	134.0	177.9	24.2	100.4
	90-100	195.7	43.0	131.4	170.1	24.1	100.1
Average		271.5	51.0	167.2	231.8	32.8	143.9
Moderate	0-10	349.4	61.7	237.7	295.3	58.6	196.1
	10-20	289.1	51.9	195.2	245.4	36.5	157.2
	20-30	254.2	47.9	174.6	237.7	32.6	130.1
	30-40	242.7	43.8	153.8	223.8	31.3	152.4
	40-50	218.2	41.7	140.7	210.6	28.8	115.0
	50-60	208.9	39.7	148.2	212.4	25.7	114.7
	60-70	176.1	40.6	127.1	208.0	28.2	102.4
	70-80	176.3	32.9	106.8	190.1	24.5	99.5
	80-90	207.6	37.4	140.3	182.2	21.9	86.6
	90-100	189.8	37.0	113.2	153.3	19.5	83.7

Average	231.2	43.5	153.8	215.4	30.8	123.8

The trace elements and heavy metals content of pea plants are shown depending on soil profile depth in the tables 2-5.

Table 2. The content of trace elements in pea plants (arable land), mg/kg

Depth, cm	**Fe**		**Zn**		**Mn**		**Cu**	
	mild	**moderate**	**mild**	**moderate**	**mild**	**moderate**	**mild**	**moderate**
0-10	134.0	131.0	33.3	40.8	43.0	40.7	8.14	7.46
10-20	131.0	107.0	25.0	37.3	39.6	37.8	5.87	6.71
20-30	100.0	126.0	27.5	27.1	42.5	38.8	5.23	6.60
30-40	110.0	112.0	23.6	30.5	44.9	38.4	7.70	5.86
40-50	116.0	137.0	25.0	24.6	41.5	37.8	5.26	5.84
50-60	116.0	122.0	27.5	27.3	46.7	35.9	5.40	7.96
60-70	126.0	98.0	28.0	23.5	50.4	42.4	5.94	10.46
70-80	139.0	111.0	28.1	21.7	45.6	47.0	5.28	8.56
80-90	113.0	115.0	27.5	20.9	45.9	45.4	5.80	7.25
90-100	128.0	127.0	27.2	22.2	49.6	42.6	5.02	9.23

Table 3. The content of heavy metals in pea plants (arable land), mg/kg

Depth, cm	**Ni**		**Co**		**Pb**		**Cd**	
	mild	**moderate**	**mild**	**moderate**	**mild**	**moderate**	**mild**	**moderate**
0-10	5.25	5.99	2.18	3.01	3.50	3.50	0.17	0.20
10-20	4.71	4.91	1.46	2.44	2.04	2.64	0.17	0.22
20-30	4.04	5.44	1.81	2.63	2.38	2.74	0.21	0.24
30-40	4.44	6.46	2.18	3.20	2.21	2.38	0.21	0.23
40-50	4.90	5.91	1.63	2.44	2.40	2.97	0.22	0.24
50-60	4.97	6.46	2.58	2.82	3.24	2.95	0.19	0.22
60-70	4.97	5.59	2.20	2.63	2.12	2.04	0.20	0.20
70-80	4.17	5.40	2.20	2.63	2.38	2.04	0.20	0.21
80-90	5.52	4.50	2.58	1.68	2.63	2.38	0.16	0.19
90-100	8.73	3.53	2.58	1.86	2.57	1.78	0.24	0.20

The maximum content of trace elements was in plants grown in the vessel with 0-10 cm layer, decreasing with depth. The content of trace elements in pea plants, on average, in the moderately sloped soil profile was equal or even higher than in the mildly sloped soil. This situation can be explained by the fact that the pea was at earliest stage on the layers of medium-washed soil, and accumulation of plant tissue with trace elements changed during the growing season due to biomass increasing.

Table 4. The content of trace elements in pea plants (virgin land), mg/kg

Depth, cm	**Fe**		**Zn**		**Mn**		**Cu**	
	mild	**moderate**	**mild**	**moderate**	**mild**	**moderate**	**mild**	**moderate**
0-10	67.3	65.3	43.3	40.2	47.3	45.7	7.48	6.94
10-20	56.3	57.3	40.9	35.7	42.7	42.0	7.24	6.10
20-30	60.3	52.7	37.2	30.6	43.7	42.0	6.33	5.39
30-40	56.7	53.0	33.2	27.0	43.7	39.7	5.80	5.17
40-50	50.7	48.3	33.7	25.9	38.7	38.0	5.20	4.94
50-60	48.3	46.3	29.5	24.2	37.0	37.7	4.88	4.98
60-70	47.7	46.0	26.4	23.5	36.3	34.7	4.60	4.61
70-80	44.7	45.7	24.4	23.1	36.0	32.0	4.55	4.35
80-90	52.0	43.0	23.0	22.4	37.3	31.3	4.20	4.24
90-100	44.3	54.3	22.7	20.1	38.7	34.3	4.14	3.85

Table 5. Content of heavy metals in pea plants (virgin land), mg/kg

Depth, cm	**Ni**		**Co**		**Pb**		**Cd**	
	mild	**moderate**	**mild**	**moderate**	**mild**	**moderate**	**mild**	**moderate**
0-10	4.12	4.12	1.67	1.64	3.47	3.75	0.039	0.039
10-20	3.81	4.10	1.66	1.62	3.61	3.70	0.040	0.036
20-30	3.54	3.70	1.66	1.20	3.80	3.47	0.039	0.037
30-40	3.55	3.20	1.32	1.15	3.14	3.24	0.023	0.027
40-50	3.44	3.20	1.26	1.10	2.66	2.99	0.024	0.027
50-60	2.94	3.19	1.16	1.15	2.79	2.99	0.023	0.027

60-70	2.94	2.93	1.45	1.17	2.62	2.42	0.018	0.027
70-80	2.66	2.88	1.08	1.23	2.66	2.14	0.018	0.021
80-90	2.61	2.34	1.08	1.21	2.66	2.14	0.010	0.021
90-100	2.61	2.33	1.18	1.15	2.50	1.99	0.017	0.020

It was noted that the absorption of microelements by pea on virgin slope soils is significantly different from arable ones. As in the experiment with arable soil, pea contained a significant amount of zinc (20.1-59.0 mg/kg), manganese (31.3-53.0 mg/kg) and iron (44.7-82.7 mg/kg). The upper horizons were distinguished by the content of zinc, manganese and copper in pea plants. Their content was higher than that of pea on the same horizons of arable soils. The iron content decreased by 1.5-2 times and was 44.7-82.7 mg/kg compared to 98-134 mg/kg on arable slopes. At the same time, the cadmium content was significantly lower (0.010-0.045 mg/kg) in pea plants on the horizons of the virgin sloping soils.

4.Conclusion

The productivity of pea cultivated on vessels with different depths was higher on mildly sloped soil compared to moderately sloped soil. Absorption of nutrients by pea in deeper horizons was less than in the plowed layer of 0-10 cm. The uptake of nutrients by pea biomass on mildly sloped soil was 13-15% greater than on moderately sloped soil.

The highest content of nitrogen, phosphorus and potassium in the biomass of plants was on low eroded soil. The content of nitrogen, phosphorus and potassium in pea biomass obtained on virgin soils was lower than on the horizons of arable slopes. The maximum content of trace elements was in plants in the 0-10 cm layer, decreasing with depth. On average, the content of trace elements in pea plants in the moderately sloped soil profile was equal to or even higher than in the mildly sloped soil.

Acknowledgements. This case study was supported with Ministry of Education and Sciences of Ukraine.

Declarations Conflict of interest: The authors have no relevant financial or non-financial interests to disclose.

References

Amede T., Gashaw T., Legesse G., Tamene L., Mekonen K., Thorne P., Schultz S., 2022, Landscape positions dictating crop fertilizer responses in wheat-based farming systems of East African Highlands, Renewable Agriculture and Food Systems, 37(S1) : S4 - S16, doi:10.1017/S1742170519000504.

Blanco-Canqui H., Ruis S.J., 2020, Cover crop impacts on soil physical properties: a review, Soil Sci. Soc. Am. J., 84(5) : 1527 - 1576, https://doi.org/10.1002/saj2.20129.

Desta G., Legesse G., Agegnehu G., Tigabie A., Nagaraji S., Gashaw T., Degefu T., Ayalew B., Addis A., Getachew T., Managido D., Bazie Z., Abathun T., Abera A., Dache A., Adissie S., Sebnie W., Feyisa T., Yakob G., Amede T., Van Rooyen A., Jat M.L. and Harawa R., 2023, Landscape-based nutrient application in wheat and the mixed farming systems of Ethiopia: farmer and extension agent demand driven approach, Front. Sustain. Food Syst, 7:1241850, doi: 10.3389/fsufs.2023.124185.

Fan F., Zhang F., Song Y., Li L., Sun J., Bao X., Guo T, Sun J., Bao X., Guo T., 2006, Nitrogen Fixation of Faba Bean (*Vicia faba* L.) Interacting with a Non-legume in Two Contrasting Intercropping Systems, Plant Soil, 283: 275 - 286, https://doi.org/10.1007/s11104-006-0019-y.

Guretzky J.A., Moore K.J., Burras C.L., Brummer E.C., 2004, Distribution of legumes along gradients of slope and soil electrical conductivity in pastures, Agron. J., 96 (2): 547 - 555, https://doi.org/10.2134/agronj2004.5470.

Harmoney K.R., Moore K.J., Brummer E.C., Lee Burras C., George J.R., 2001, Spatial legume composition and diversity across seeded landscapes, Agron. J., 93 (5): 992 - 1000, https://doi.org/10.2134/agronj2001.935992x.

Hauggaard - Nielsen, H., Holdensen, L.,Wulfsohn, D. *et al.* 2010, Spatial variation of N_2-fixation in field pea (Pisum sativum L.) at the field scale determined by the ^{15}N natural abundance method, Plant Soil, 327: 167 - 184, https://doi.org/10.1007/s11104-009-0043-9.

Hladky J., Novotna J., Elbl J., Kynicky J., Juricka D., Novotna J., Brtnicky M., 2016, Impacts of Water Erosion on Soil Physical Properties, Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 64 (5): 1523 - 1527, http://dx.doi.org/10.11118/actaun201664051523.

Kalpana B., Sikder A.H.F., Khanom S., Hossain M.F., Parveen Z., 2015, Nutrient Uptake by Plants from Different Land Types of Madhupur Soils, The Bangladesh Journal of scientific research, 28: 113 - 121, DOI:10.3329/bjsr.v28i2.26782.

Kaur H., Nelson K. A., Singh G., Kauret G. et al., 2023, Landscape Position and Cover Crops Affects Crop Yields in a Terrace-Tiled Field, Agricultural Water Management, 289, 108517, https://doi.org/10.1016/j.agwat.2023.108517.

Kharytonov M., Bagorka M., Gibson P., 2004, Erosion effects in the central steppe chernozem soils of Ukraine. I.Soil Properties. Agricultura, 3(1):12 - 18.

Kharytonov M., Velychko O., 2017, Crops adaptation management in the conditions of steppe landscape of Ukraine, Agriculture and Forestry, 63 (3): 189-198, DOI: 10.17707/AgricultForest.63.3.19.

Magrini M.B., Anton M., Cholez C., Corre-Hellou G., Duc G., Jeuffroy M.H., Meynard J.M., Pelzer E., Voisin A.S., Walrand S., 2016, Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? Analyzing lock-in the French agrifood system, Ecol. Econ., 126: 152 - 162, https://doi.org/10.1016/j.ecolecon.2016.03.024.

Mawois M., Revoyron E., Vidal A., Jeufroy M. H., Le Bail M., 2019, Transition to legume-based farming systems requires stable outlets, learning and peer - networking. Agron. Sustain. Dev. 39, 14, https://doi.org/10.1007/s13593-019-0559-1.

Mesfin S., Gebresamuel G., Haile M., Zenebe A., 2023, Potentials of legumes rotation on yield and nitrogen uptake of subsequent wheat crop in northern Ethiopia. Heliyon, 9 (6): e16126, https://doi.org/10.1016/j.heliyon.2023.e16126.

Miguez, F.E., Bollero, G.A., 2005, Review of corn yield response under winter cover cropping systems using meta-analytic methods, Crop Sci., 45 (6) : 2318 - 2329, https://doi.org/10.2135/cropsci2005.0014.

Moges A., Holden N.M., 2008, Soil fertility in relation to slope position and agricultural land use: a case study of Umbulo catchment in Southern Ethiopia, Environmental Management 42: 753 - 763. DOI: 10.1007/s00267-008-9157-8

Munoz J.D., Steibel J.P., Snapp S., Kravchenko A.N., 2014, Cover crop effect on corn growth and yield as influenced by topography, Agric. Ecosyst. Environ., 189 : 229 - 239, https://doi.org/10.1016/j.agee.2014.03.045.

Stagnari F., Maggio A., Galieni A., Pisante M., 2017, Multiple benefits of legumes for agriculture sustainability: An overview, Chem. Biol. Technol. Agric., 4, 2, https://doi.org/10.1186/s40538-016-0085-1

Thomas, R.L., Sheard, R.W., Mayer, J.R., 1967, Comparison of conventional and automated procedures for nitrogen, phosphorus and potassium analysis of plant material using a single digestion, Agron. J., 59(3): 240 - 243.