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THE CONDITION OF AGRICULTURAL SOILS IN PRIMORJE-GORSKI KOTAR COUNTY, CROATIA

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ABSTRACT

In the context of sustainability and the use of natural resources, it has been often shown that agricultural soils do not reach their productive function to their full potential. The ability of the soil to provide plants with appropriate growing conditions is reduced due to soil degradation. Documenting soil conditions aimed at determining soil quality indicators in relation to soil management enables to identify the type and location of degradation in order to suggest corrective measures to farmers for the soil fertility improvement. Since the basis for the successful agricultural production is appropriate soil quality from one side, and the soil quality improvement, monitoring and protection are priority according to the current legal acts, the new European Soil Strategy for 2030 and the Soil Act planned for 2023 from another side, the soil testing laboratory of the Center for Agriculture and Rural Development of Primorje-Gorski Kotar County (PGKC) conducted the initial studies in 2019. Soil samples from the agricultural field in PGKC were tested using fast methods for following parameters: soil pH, total $CaCO_3$*, nitrate content, content of plant available phosphorus, potassium and magnesium, total* *calcium, aggregate stability and electrical conductivity. The test results idnicated the relative condition of the soil at different locations and in different crops. In addition, the results served as a basis for the sustainable soil management measures suggestion to the farmers in PGKC.*

Key words: *agricultural soil, soil degradation, soil analysis, soil condition, soil parameters*

1. INTRODUCTION

In the context of sustainability, it has often been shown that agricultural soils do not reach productive function to their full potential. The ability of the soil to provide plants with appropriate growing conditions is reduced due to the soil degradation. Anthropogenic reasons of soil degradation are caused due to the inadequate soil management (e.g. Eswaran et al., 2001) and intensive agricultural production (e.g. Bašić, 1994), which decreases land's production capacity by the loss of soil fertility and biodiversity (Maximillian et al., 2019).

According to the Mission Board for Soil Health and Food of the European commission (Veerman *et al.*, 2020), 60-70% of soils in the European Union (EU) are degraded as a direct result of unsustainable management practices. Soils in the Mediterranean region were shown to be highly susceptible to soil degradation (Lahmar and Ruellan, 2007), high erosion caused by water and wind (Panagos et al., 2020), and to contain the lowest level of organic matter (Aguilera et al., 2013). Furthermore, increase of salinity has also been reported (Stolte et al., 2016). Likewise, significant fertility decrease is observed in Croatian agricultural soils (Bašić, 1994). According to Hefer et al. (2019), the main problems in Croatian soils are low level of organic matter, soil acidity and low plant available phosphorous content. In their study, out of 9.868 soil samples from different sites across Croatia, 90% of samples had organic matter content below 3%, while in the 55,4% of samples the organic matter level was below 2%. An acid reaction and an insufficient content of plant-available phosphorous were identified in 59% and 37.3% of the soil samples, respectively.

To protect soils on the same legal basis as air and water, EU have launched or presented soil legal documents. Soil Health Law is present legislative proposal which will be prepared by the end of 2023 because there is currently no legislation dedicated to soil among Member States (European Commision, 2022). The EU *Soil Strategy* for *2030* (European Commision, 2021a) has set a vision and objectives to achieve healthy soils by 2050, which is planned to achieve by employing concrete actions by 2030. These actions will focus on preventing the degradation and the recovery of degraded soil by sustainable use and recovery measures including the reducing of soil nutrients losses for at least 50%. Furthermore, it is expected that those measures would become a rule, and that the sustainable soil management would become a common practice by 2030. Sustainable soil management include a set of practical measures which enables the preservation or recovery of soil health (Veerman et al., 2020).

At the national level in Croatia, there are legal documents that consider soil protection. Strategic Plan of the Common Agricultural Policy of the Republic of Croatia 2023 – 2027 (European Commision, 2021b) have included improvement of the soil conditions in priority interventions. The Act on Agricultural Land (NN 20/18, 115/18, 98/19) regulates maintenance and protection of agricultural land and the agricultural land way of use. The Regulation on the Protection of Agricultural Land (NN 71/2019) determines the substances that pollute the agricultural land and their maximally permitted amount in the soil in order to prevent the soil pollution, to protect it from degradation and to maintain it in a favorable habitat for healthy food. Methodology for monitoring the condition of agricultural land (monitoring and soil fertility testing), minimum area for monitoring the condition of agricultural land, information system for the protection of agricultural land is ruled by the Regulation on Methodology for Monitoring the Condition of Agricultural Land (NN 20/18, NN 115/18). The Regulation on Agrotechnical Measures (NN 22/2019) regulate agrotechnical measures that must be implemented for the preservation of prudential value by owners and possessors of agricultural land during the cultivation of agricultural land.

The challenge in relation to all mentioned national documents are, besides other, small size of the farms (less than 1ha), which are mostly not subjected to the legal acts and suggested monitoring and measures. The unsuitability of the fragmented, dislocated and small production filed size has been determined as major business and economic issue in Croatia (Tomić, 2014). To decrease the number of fragmented and size of small farms, consolidation of agricultural land has been regulated by the Act on Consolidation of Agricultural Land of the Republic of Croatia (NN 51/15). Regardless of the attempts to increase the filed size in Croatia, there is still high number of small farms. However, in the Primorje-Gorski kotar County (*PGKC)*, the agricultural land could not be significantly consolidated. The reasons for fragmentation are geographical and related constraints, especially in Gorksi kotar microregion, which belongs to the group of *hilly* and *mountainous areas*, and islands (Plan razvoja primorsko-goranske županije za razdoblje 2022.-2027., 2021). Another important agricultural aspect, as a consequence of geographical and related constraints, is diversification of the agricultural production where producers are not solely orientated on primary agricultural production. The diversification of agricultural production includes e.g. agritourism activities and agricultural product processing.

Because of the *PGKC specifics* (geographical constrains) and higher number of farms below 1 ha in size, which are mostly excluded from the regulations, from one side, and the priority to implement sustainable soil management practices from another side, the soil laboratory of the Center for Agriculture and Rural Development of PGKC commenced the initial basic soil pilot studies in 2019. The intention was to advise agricultural producers on sustainable soil management practices regardless of the production filed size. The goals were to: i) collect and analyze soil samples; ii) approximate the soil conditions of agricultural land; iii) recommend sustainable management practices; vi) create guidelines for further studies and determine additional laboratory equipment for standard analyzes. Since the precondition to sustainable practices recommendation and guidelines creation is to determine the current condition of the agricultural soil, the aim of this study was to and assess the relative condition of the soil at different locations and in different crops in PGKC.

2. MATERIALS AND METHODS

2. 1 Soil sampling

The soil samples were taken by farmers from 2019 to 2021 from different crops and location in Primorje-Gorski Kotar County (PGKC). Farmers were given instructions on how to take soil samples. To motivate the farmers to send soil samples, analyses and recommendations were free of charge.

Samples consisted of 10-20 sub-samples taken at random across the field in the shape of the letter „W". The sub-samples were placed in a plastic can and mixed thoroughly by hand or trowel. A sample between 0.5 and 1.5 kg was placed into a plastic bag and with all required information sent to the Center for Agriculture and Rural Development of PGKC by post mail. For vegetable and arable crops, samples were taken from 0-30 cm, for hazelnut and berry fruit from 0-40 cm, and for vine and fruit with deeper roots from 0-30 cm and 30-60 cm.

The samples were categorized into three groups for the analysis: "Coast and Islands" representing samples from the coastal region; "Gorski Kotar" for those originating from the continental part; and "PGKC" for samples that lack precise information on sampling location.

2. 2 Soil analyses

The samples were left for 24 hours at the room temperature to dry. Dry soil was sieved using 2 mm mesh sieve and analysed. The plant available phosphorus (P_2O_5), magnesium (MgO), total calcium (Ca), total carbonates ($CaCO_3$) and nitrate content were determinated. In addition, the soil salinity, aggregate stability and pH value were assessed. For P_2O_5, K_2O, MgO, total Ca content, and soil salinity SK300 Soil Management Kit (Palintest, UK) fast method was used. The SK300 Soil Management Kit provides macronutrient testing with visual testing apparatus. To measure pH, pH meter was used. The calcimeter (Eijkelkamp) was used to determine the total $CaCO_3$. Nitrachek was used for the quantitative assessment of nitrate content of soil samples (Eijkelkamp), while aggregate degradation was assessed by apparatus for the wet sieving (Eijkelkamp). The optimum values that were taken as a reference for analyses factors are presented in Table 1.

Table 1. Optimal content range of P_2O_5, K_2O, MgO, total Ca, total $CaCO_3$, soil salinity, aggregate stability and the optimal pH range

Factor	Optimal value
P_2O_5	17 - 25 mg/100gr of soil
K_2O	20 - 30 mg/100gr of soil
MgO	5 - 25 mg/100gr of soil
Total Ca	40 - 60 mg/100gr of soil
EC value	0 - 2
Agregate stability	10 - 20%
Total $CaCO_3$	10 - 30
Nitrate	2.1 - 4 mg/100gr of soil
pH (in H_2O)	6.6 - 7.3

Source: Authors

2. 3 Statistical analyses

To describe the basic features of the data descriptive statistics was used. One-way analysis of variance (ANOVA) was calculated and Duncan test was used to investigate the influence of location on tested parameters. p-Values lower or equal to 0.05 were considered statistically significant. For multiple variable analyses Pearson's correlation coefficient (r) was used. The data was analysed with the statistical software Statgraphics v. 16.1.11.

3. RESULTS

Out of 54 soil samples, precise sampling location was known for 65% of the samples. The highest percentage (48%) of soil samples were taken from the Gorski kotar site (Table 2).

Table 2. Location of soil sampling

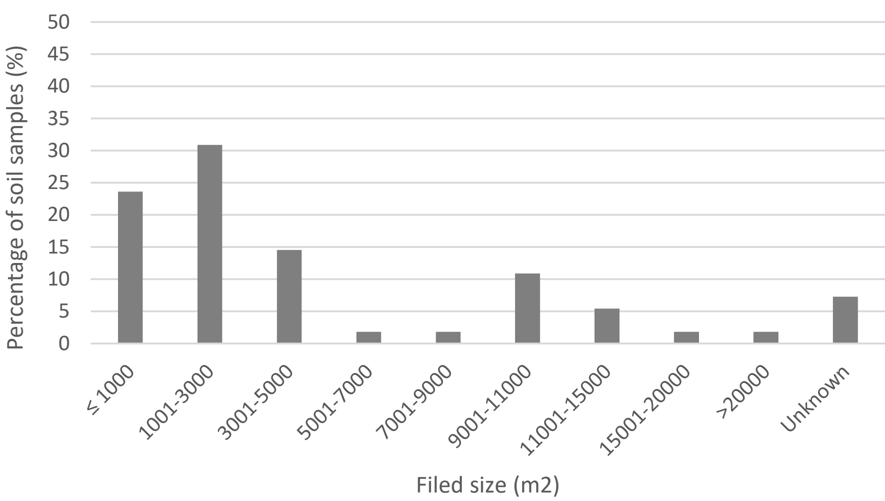
Sampling location	Percentage of soil samples (%)
Coast and islands	17
Gorski kotar	48
PGKC	35

Source: Authors

Soil was sampled from fields where vegetables, fruits, olives, vine, medicinal and aromatic plants and green manure cover crops are grown. The highest percentage of samples were taken from vegetable fields (37%), followed by fruits (24%).

In most of the cases (31%), the size of the production fields from where the soil samples were taken were 1.001 – 3.000 m^2, followed by the size of 1.000m^2 or less (Figure 1).

Figure 1. The size of the production fields (m^2)



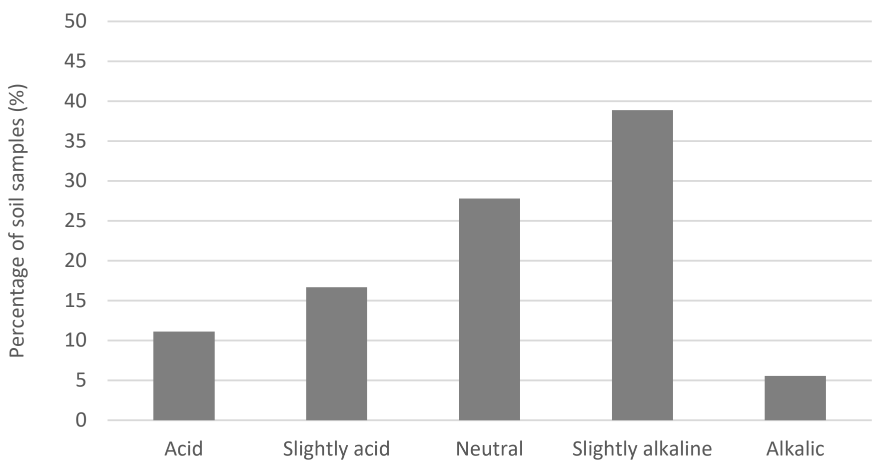
Source: Authors

About 70% of Croatian farmers cultivate less than 5 ha of agricultural land, the production is fragmented (Strategija poljoprivrede do 2030, 2022) and the production filed size are mostly small (Tomić, 2014), which is relatively similar to the results from this study where in the 75% of fields from where the soil samples were taken are not exceeding 0.5 ha.

The pH value ranged from acid to alkaline, where 39% of samples were slightly alkaline (Figure 2). Different soil pH reaction is reported for Croatian soils collected from different sites across Croatia. According to Hefer et al. (2021) the highest percentage of soil samples from Croatian soils are acid (59%), while Herak Ćustić et al. (2005) reported that 47% of soil samples have neutral reaction. In this study, a slightly alkaline reaction predominates, which is an unexpected result, considering that the highest percentage of soil samples were taken from the Gorski kotar site where an acidic soil reaction predominates (Martinović, 1994; Martinović et al., 2009).

It seems that the agricultural practices employed by farmers do not significantly affect the soil pH.

Figure 2. pH value of soil samples



Source: Authors

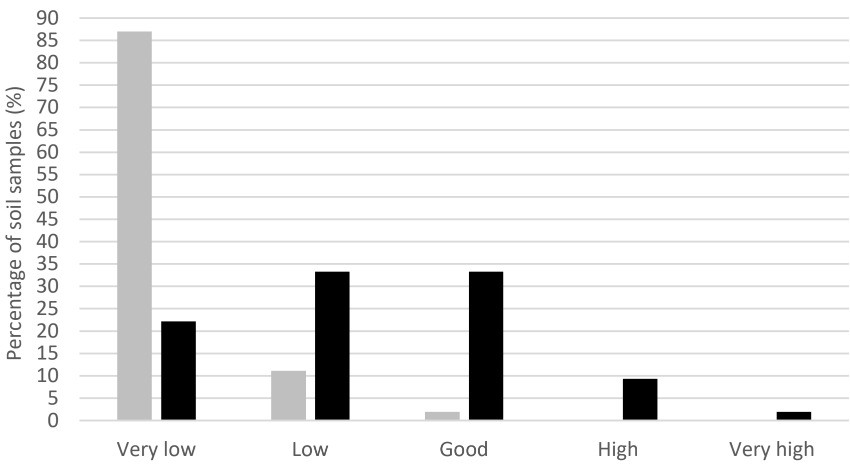
Almost all soil samples had low level of total carbonates (98%). The content of magnesium and calcium was optimal in the most of the samples (76% and 91%, respectively). Total carbon could decrease the acidity, provide the availability of Ca and MgO and have impacts on soil structure (Rowley et al., 2020). In this study, the low content of total carbonates was not associated with the availability of total Ca and MgO.

The content of plant available phosphorus (P_2O_5) was very low in 87% of samples, while the percentage of samples with either good or low content of potassium was equal (33%) (Figure 3). If the samples are divided in two groups, with sufficient and insufficient content of K, there is a higher percentage (55.5%) of samples with insufficient K content.

As in this study, the content of plant available P_2O_5 is often reported as insufitient in Croatian soils (Hefer et al., 2021) and worldwide (Alewell et al., 2020). The content of plant available P is especially low in acid soils (Zheng, 2010) which is not in line with the results from this study, where slightly alkalic reaction predominates. Unlike in this study, the soils in Croatia, to a higher extent, do not lack potassium (Hefer et al., 2021). The relatively lower level of K could be due to the unsuitable fertilization with potassium fertilizers and/or exclusion of organic fertilizers (Madaras et al., 2014).

The aggregate stability is, in most of the samples (35%), very stable, while the percentage of unstable or slightly unstable is low (2% and 6%, respectively). If the aggregate stability is divided in two groups, unstable and stable, the percentage of samples with stable aggregates is slightly higher (54%). Aggregate stability is affected by long-term tillage (Norton et al., 2006), content of Ca (Škorić, 1991) and K_2O (Phocharoen et al., 2018), soil organic carbon, clay and silt content, and the presence of carbonates and gypsum (Amézketa, 1999). It seems, according to the results of this study, that the relatively low content of K2O and the low levels of total carbonates do not play a crucial role in soil aggregate stability. However, the optimal level of total Ca in this study could affect the stability of soil aggregates (Škorić, 1991).

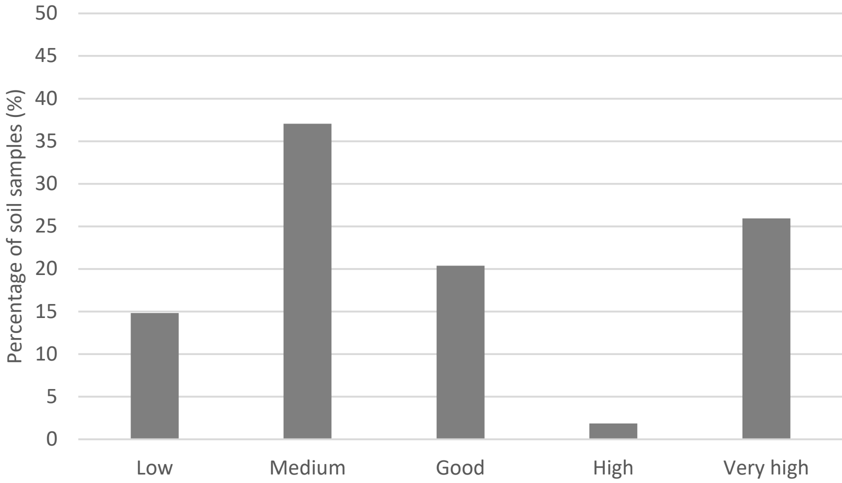
Figure 3. Content of plant available phosphorus (P_2O_5) and potassium (K_2O) in the soil samples



Source: Authors

The results show variation in the nitrate content (Figure 4). In 37% of soil samples, the nitrate content was optimal, followed by a very high content in 26% of the samples. Nitrate content in soil is one of the indicators of available nitrogen to plants (Griffin et al., 2009) but the levels of nitrogen can oscillate depending on soil water movement (Li et al., 2019) and application of fertilizers. The variations in results observed in this study may be attributed to differences in sampling seasons, and consequently, variations in soil water dynamics, rates, and timing of nitrogen fertilizer applications, whether organic (e.g., urea) or mineral (e.g., calcium ammonium nitrate).

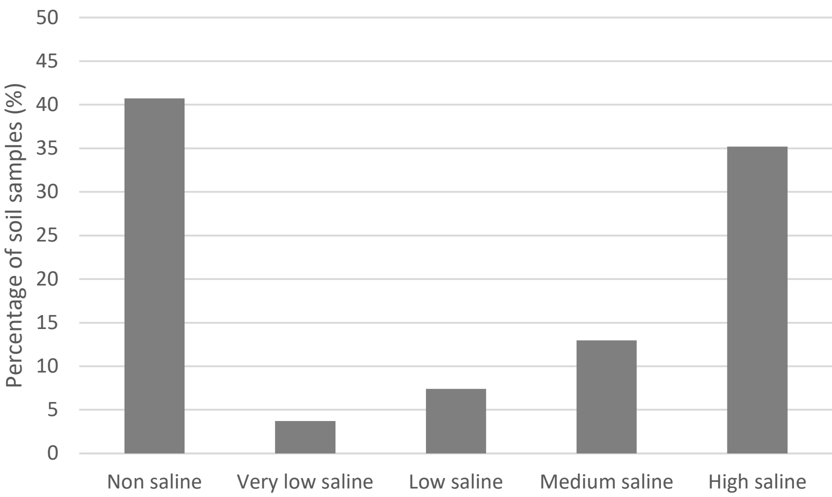
Figure 4. Content of nitrates in soil samples



Source: Authors

The result showed that the most samples were (Figure 5) in the category of unsalted soil and highly salted (41% and 35%, respectively). The contrary result could be attributed to unsustainable soil management practices. Inappropriate application rate of fertilizers and soil amandments (Provin and Pitt, 2001; Zaman et al., 2018) and inappropriate type of fertilizers (Zaman et al., 2018) could significantly increase soil salinity.

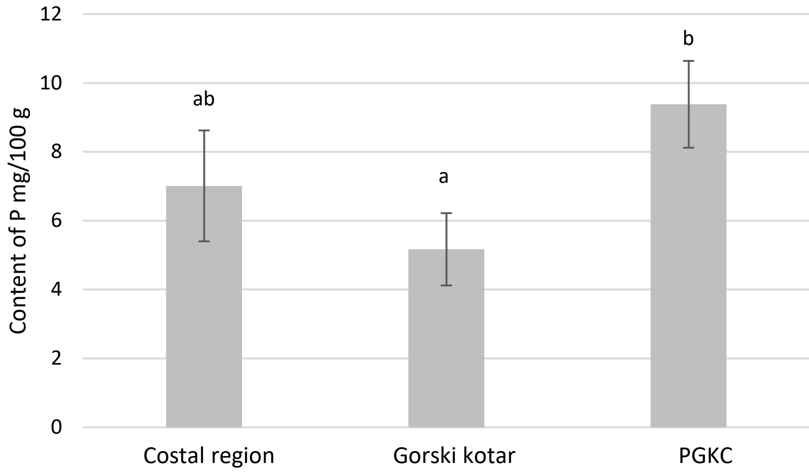
Figure 5. Salinity level of soil samples



Source: Authors

The location of sampling had no influence on tested parameters, except for total Ca level and content of plant available phosphorus. The significant difference has been in the content of P_2O_5 between locations of Gorski kotar sites and PGKC location ($p>0.05$). There was no significant difference in the content of P_2O_5 between samples from Gorski kotar microregion and costal and island sites (Figure 6).

Figure 6. Influence of the sampling location on the plant available phosphorus (P_2O_5) level

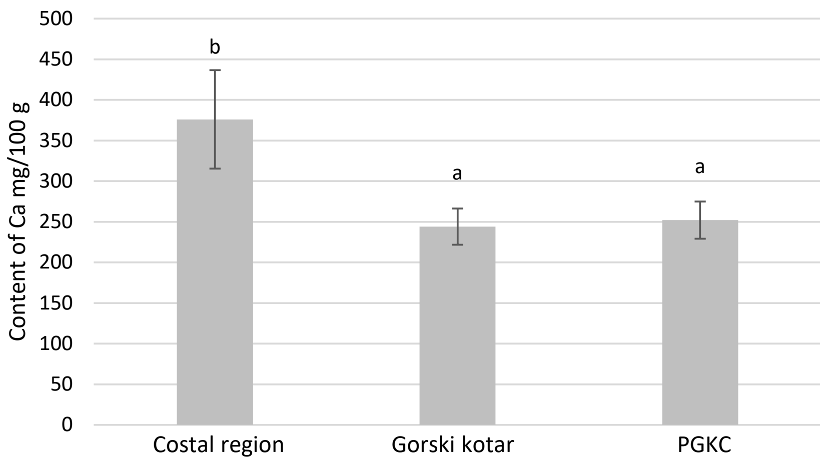


The different letters above bars indicate significant difference between localities in the P content (p>0.05).

Source: Authors

The content of Ca was significantly higher in the samples from costal location then in the samples from Gorski kotar (p>0.05) (Figure 7).

Figure 7. Influence of the sampling location on the total calcium (Ca) level



The different letters above bars indicate significant difference between localities in the Ca content (p>0.05).

Source: Authors

Calcium naturally occurs in soil, with high concentrations typically found in carbonate soils (Vukadinović and Vukadinović, 2011). Although the total $CaCO_3$ was low in this study, the costal region could have higher Ca content due to the soil type. Different soil types could have naturally different Ca concentration depending on the parent material (Mengel and Kirkby, 2012) and different climatic conditions in a region in one hydrological year (Guo et al., 2017; Luo et al., 2023). The calcium cation can be easily leached from the soil by heavy rainfall during the winter period (Neilsen and Stevenson, 1983).

The results showed significant positive correlation between pH and total $CaCO_3$ ($p>0.05$; $r= 0.473$) and total Ca ($p>0.05$; $r= 0.470$). The total $CaCO_3$ had significant negative correlation with K ($p>0.05$; $r= -0.316$). The soil aggregate stability has showed positive correlation with potassium ($p>0.05$; $r= 0.291$) and significant negative correlation with soil salinity ($p>0.05$; $r= -0.426$). The significant associations are presented in the Table 3.

Table 3. Intensity of the association between tested parameters estimated by the correlation coefficient (r)

	Total carbonates	Potassium	Total calcium	Salinity
pH	0.473	n.s.	0.47	n.s.
Total carbonates	n.s.	−0.316	0.478	n.s.
Potassium	n.s.	n.s.	n.s.	n.s.
Aggregate stability	n.s.	0.291	n.s.	−0.426

n.s. = not significant

Source: Authors

The pH value increases with the increase in $CaCO_3$ and calcium levels (Vukadinović et al., 2008), which is consistent with the findings of this study. However, in some cases, the relationship between pH and $CaCO_3$ varies due to soil complexity, where other factors (e.g., different soil-forming factors or soil types) could influence their association (Lin et al., 2017).

It has been demonstrated that potassium supports aggregate stability (e.g., Kaewmano et al., 2009), as confirmed by the results of this study. Conversely, aggregate stability is negatively affected by salinity (Kaewmano et al., 2009; Vukadinović and Vukadinović, 2018; Bless et al., 2022), which aligns with the findings of this study.

4. CONCLUSION

In this study, soil samples were analysed using rapid laboratory methods. The soil was sampled from various crops and locations in the Primorje Gorski Kotar County (PGKC). In 75% of the cases, the size of the production fields from which the soil samples were taken was up to 5,000 m2. The highest percentage of samples were collected from vegetable fields (37%), followed by fruit orchards (24%).

The pH values were relatively satisfactory in most cases, with lower percentages of acidic and slightly acidic soil samples (11% and 17%, respectively). Total carbonate ($CaCO_3$) content was low, plant-available phosphorus (P_2O_5) content was very low, and potassium (K_2O) content was relatively low. Salinity and nitrate content showed high variation, possibly due to differences in sampling times (before or after nitrogen fertilization), inappropriate application rate of fertilizers or to changes in water dynamics. Total calcium (Ca) and magnesium (MgO) content were optimal, while aggregate stability was adequate in most cases (54%), suggesting minimal erosion issues in the fields. Furthermore, despite the low total carbonate levels, optimal Ca and MgO content were observed.

There was a significantly higher total Ca content in the coastal region compared to the Gorski kotar microregion. Associations were identified between $CaCO_3$ and K_2O, with K_2O showing a negative correlation with $CaCO_3$. Aggregate stability was positively correlated with K_2O.

Based on the results, it is recommended to implement sustainable soil management methods in both the Gorski Kotar and coastal regions, as well as on the islands, where regulation of plant available phosphorus, potassium, and nitrate levels is needed. Consequently, salinity levels would decrease where necessary.

Rapid methods for analyzing soil samples could be employed to obtain overall information on soil condition and serve as a recommendation basis for farmers. These rapid analyses could be recommended to farmers for independent basic monitoring of soil condition. However, for more precise results, it is suggested to equip the laboratory of the Center for Agriculture and Rural Development of PGKC with additional standard laboratory equipment, especially for studying organic matter, which plays a crucial role in improving soil quality. The results from this study will also serve as a basis for creating sustainable guidelines for farmers in PGKC to improve soil quality and the health of agricultural soils.

Further studies suggest conducting more extensive sampling and grouping samples by location and crops to enhance soil health, quality, and fertility to a greater extent.

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STANJE POLJOPRIVREDNIH TALA U PRIMORSKO-GORANSKOJ ŽUPANIJI, HRVATSKA

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Ključne riječi: *poljoprivredno tlo, degradacija tla, analiza tla, stanje tla, parametri tla*