Scientific Papers. Series A. Agronomy, Vol. LXVI, No. 1, 2023
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

CHARACTERIZATION OF AN AGROFORESTRY SYSTEM FROM WEST OF ROMANIA THROUGH SUSTAINABILITY INDICATORS OF SOIL

Romina MAZĂRE, Mădălina IORDACHE

University of Life Sciences "King Mihai I" from Timisoara, 119 Calea Aradului Street, Timisoara, Romania

Corresponding author email: mada_iordache@yahoo.com

Abstract

The agroforestry systems in Romania are rare and low studied, although the advantages provided by these systems to agriculture are multiple. The aim of this research was to use several soil indicators widely used as indicators of soil sustainability to characterize an agroforestry system from western Romania, Timiș County (45.45418°N, 20.90334°E). The studied agroforestry system was a silvoarable ecosystem and consisted of two components: a woody perennial plant represented by Euro-American hybrid poplar trees (Populus deltoides x Populus nigra) and an agricultural crop - rapeseed (Brassica napus L.) - hybrid LG Architect. The soil parameters analyzed for both components were pH, humus, total nitrogen, plant-available phosphorus, and plant-available potassium. There have been found higher values of the soil parameters pH, humus, plant-available phosphorus and plant-available potassium in the soil cultivated with rapeseed than those of the soil planted with hybrid poplar, and statistically significant (p<0.01) correlations between several soil factors of the two components of the silvoarable system: between pH and plant-available potassium in the Populus spp. plantation and between humus and plant-available phosphorus in the rapeseed crop. The findings of this study show benefits expressed as nutrient increase of soil for the rapeseed crop in the silvoarable system poplar-based and emphasize the favourable association of these two types of plants: trees and crops.

Key words*: poplar, Populus, rapeseed, canola, silvoarable, nutrients.*

INTRODUCTION

Agroforestry is an agricultural practice which combines trees with crops and/or livestock, and which is practised on 15 million hectares equivalent to 9% of the cultivated agricultural land or to 3.6% of the territorial land (or on 52 million hectares if the reindeer is included) in the European Union (Augère-Granier, 2020), and respectively on 1 billion hectares and by over 1.2 billion people worldwide (United Nation Food and Agriculture Organization - FAO, 2017).

The agroforestry systems in Romania are low studied despite their multiple advantages (Kay et al., 2019) for crop protection and production, soil protection and environmental buffer in climate changes mitigation. When these types of systems are studied in Romania, the investigations are predominantly focused on silvopastoral systems (Hartel et al., 2018; Smith et al., 2022) or on forest shelterbelts (Malschi et al., 2010; Mihaila et al., 2022a; 2022b). The Romanian potential in agroforestry absolute area is large as compared to other countries in Europe (den Harder et al., 2017). According to Augère-Granier (2020) citing the Proceedings of the 5th World Congress on Agroforestry 2022, Romania is the fourth funded country of the European Union through financial supporting programmes in agroforestry, after Spain, France, and Italy, which reveals the increasing interest on this type of agriculture due to its benefits and recognition as a main tool in mitigate several environmental challenges, such as climate change, protection of water, soil, and biodiversity resources, alongside with the reduction of the pesticide dependence and animal welfare threatening as agriculture consequences. Because of the rather recent interest in agroforestry, in Romania this activity is often not clearly recognized with this name, although this exists and this is performed and sometimes even funded and supported through financial national instruments as part of the common agricultural policy (CAP) of the European Union.

The hybrid poplars (*Populus* spp.) present several characteristics which recommend them to be used as part of the silvoarable agroforestry systems, such as: they are perennial plants with fast growth and weight gain, necessitate long period of crop rotation which make them very comfortable for farmers (between 2 and 40 years, depending on the local climate and on the purpose of cultivation) (Manevski et al., 2019), they have deep resistant root (Babi et al., 2023), able to explore the deep layers of the soil profile, and thus accessing different pools of water and nutrients, are excellent drainers of the water-excess soils (Manevski et al., 2019), increase the nutrient concentrations and availability in the vicinity crops (Pardon et al., 2017).

The aim of the paper is to describe a silvoarable agroforestry system from west side of Romania which combine hybrid poplar trees with rapeseed crop through several soil parameters widely used as sustainability indicators in ecosystem assessments: pH, humus, total nitrogen, plant-available phosphorus, and plant-available potassium, with the goal to emphasize the favourable association of these two types of plants: trees and crops.

MATERIALS AND METHODS

The study has been conducted in an agroforestry system (Figure 1) located in Timiș County (45.45418°N, 20.90334°E), Romania and aimed to characterize it through several soil parameters widely used as indicators of soil sustainability. The studied agroforestry system is a silvoarable ecosystem according to FAO three-types classification of agroforestry (2017) and consisted of two components: a woody perennial plant represented by Euro-American hybrid poplar trees (*Populus deltoides* × *Populus nigra*) and an agricultural crop - rapeseed (*Brassica napus* L.) - hybrid LG Architect bordered by the poplar plantation. The soil parameters analyzed for both components were pH, humus, total nitrogen (total N), plant-available phosphorus (plant-available P), and plant-available potassium (plant-available K), which are main physical and chemical indicators used in describing the sustainability of agroecosystems (Augusto et al., 2017). The soil of the analyzed agroforestry system is vertisol (World Reference Base for Soil Resources, 2022). The soil samples have been collected at different depths: in the poplar plantation at three depth: 0-10 cm, 10-20 cm, and 20-30 cm, and in the rapeseed crop at 10 cm. These intervals of sampling have been chosen taking into consideration the tillage management in the two plant types of the agroforestry system, respectively: no soil workings in the poplar plantation for eight years which determined non disturbed soil profile, and conventional soil workings in the rapeseed crop which meant the disturbing and mixing of the soil layers on a depth by 30 cm, a sufficient reason to sample this soil only for the depth of 0-10 cm. The soil analyses have been performed by OSPA (Office for Pedological and Agrochemical Studies) Timiș using the following methodology: determination of pH - SR 7184-13:2001-PS-03; determination of humus - STAS 7184/21-82-PS-01; determination of the total N - STAS 7184/2-85-PS-08; determination of the plant-available P - STAS 7184/19-82-PS-02; determination of the plant-available K - STAS 7184/18-80-PS-06. The statistical analysis has been performed using the software IBM SPSS 28.0.0.0.

Figure 1. The agroforestry site: rapeseed crop (*Brassica napus* L.) bordered by poplar (*Populus* spp.) plantation

RESULTS AND DISCUSSIONS

The values of the aimed soil parameters are listed in Table 1 both for rapeseed crop and for poplar plantation by depth intervals. Also, for the soil factors of the poplar plantation there has been calculated the mean of the three depths in order to compare them with the values recorded in the soil of rapeseed crop.

Table 1. The soil parameters (mean values) of the two components (rapeseed crop and *Populus* spp. plantation) of the studied agroforestry ecosystem, by soil depths

Soil depth (cm)	Soil parameters in *Populus* spp. (hybrid poplar) plantation (mean values)				
	pH	Humus (%)	Total N (%)	Plant available P (ppm)	Plant available K (ppm)
0-10 cm	6.55	2.33	0.14	4.38	126
10-20 cm	6.26	1.76	0.12	4.14	91
10-30 cm	6.27	1.06	0.13	5.65	97
Means of soil depths	6.36	1.71	0.13	4.72	104.66
Standard Deviation	0.16462	0.63611	0.1000	0.81144	18.71719
Soil depth (cm)	Soil parameters in *Brassica napus* (rapeseed) crop (mean values)				
	pH	Humus (%)	Total N (%)	Plant available P (ppm)	Plant available K (ppm)
0-10 cm	6.42	2.07	0.12	18.78	124
Standard Deviation	0.24434	0.65010	0.00577	15.61453	15.87451

According to ICPA Romania and considering the cultivation technology (normal/intensive), the values of the chemical indices of soil for both plant types were classified as presented in Table 2. Thus, there was identified a low supply with nitrogen of both plants and low-moderate with humus.

Table 2. The supply degree of soils with nutrients (rapeseed crop and *Populus* spp. plantation)

Soil depth (0-30 cm)	pH	Humus (%)	Total N (%)	Plant available P (ppm)	Plant available K (ppm)
Populus spp. (hybrid poplar) plantation (mean values)	6.36 low acid	1.71 low	0.130 low	4.72 very low	104.66 moderate
Brassica napus (rapeseed) crop (mean values)	6.42 low acid	2.07 moderate	0.126 low	18.78 moderate	124.00 moderate

There has been found lower values of the soil analyzed parameters (pH, humus, P and K) in the soil planted with hybrid poplar versus those of the soil cultivated with rapeseed (Figure 2), but the differences between means were not statistically significant ($p>0.01$, $p>0.05$) (paired-samples t-test) (Table 3).

There was compared the results achieved for the hybrid poplar plantations to other findings obtained in 2019 for the same area of study which aimed at that time to characterize the soil of an agricultural land for establishing its suitability for the cultivation of energy hybrid poplar (Cândea-Crăciun et al., 2019). The available data used for comparison have been pH, humus, and total nitrogen (Table 4). The results showed differences like a slightly increase of the pH value, a slightly decrease of the humus content, and a considerable decrease of the total nitrogen content.

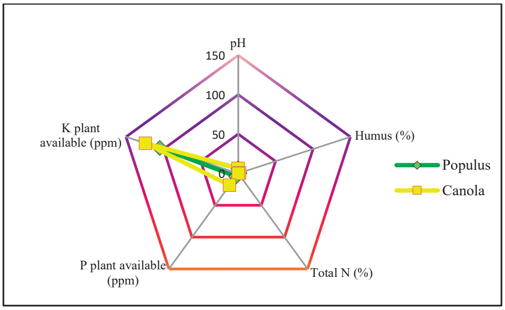

Figure 2. The soil parameters (mean values of soil layers depths) of the two components (rapeseed crop and *Populus* spp. plantation) of the studied agroforestry system

Table 3. Paired-samples t-test showing non-significant ($p>0.01$, $p>0.05$) differences between the soil parameters of the two components of the agroforestry ecosystem

Variables (means)	Mean	t	df	Significance (1-tailed)	Significance (2-tailed)
pH Hybrid poplar - pH Rapeseed	-0.0600	-0.933	2	0.225	0.449
Humus Hybrid poplar - Humus Rapeseed	-0.3566	-0.746	2	0.267	0.534
Total N Hybrid poplar - Total N Rapeseed	0.0020	0.480	2	0.339	0.678
P plant available Hybrid poplar - P plant available Rapeseed	-14.0566	-1.487	2	0.138	0.275
K plant available Hybrid poplar - K plant available Rapeseed	-19.6700	-2.409	2	0.069	0.138

Table 4. The supply degree of soils with nutrients for the study site, *Populus* spp. plantation, 2022 versus 2019

Soil depth (0-30 cm)	pH	Humus (%)	Total N (%)
2019 (Cândea-Crăciun et al., 2019)	5.90	1.76	0.17
2022	6.36	1.71	0.13
Difference	+1.07%	-2.85%	-23.53%

Although different from other studies, the pH values recorded in our study are situated within the recommended and appropriate range of pH values for the hybrid poplar growth, meaning between 5 and 8 (Hjelm et al., 2018). The values of the soil pH both in poplar plantation and in rapeseed crop remained in the appropriate range to avoid soil degradation and nutrient unavailability through acidity.

However, the attention should be paid to the humus, nitrogen, phosphorus and potassium content, because these nutrients are very important for the poplars (Rennenberg et al., 2010). Low content of humus in energy hybrid poplar plantations had been reported previously (Demo et al., 2013). The low supply with humus in the hybrid poplar plantation (Table 2) probably shows the poplar contribution to the nitrogen cycle through humus mineralization (Savin et al., 2019) because the chemical supplementary fertilization lacks in this plantation. A low non statistically significant decrease of the total nitrogen has been shown in the soil of rapeseed crop versus the soil of hybrid poplar, although the rapeseed crop has been nitrogen fertilized (RhizoStart 8-30-0 fertilizer - 2 weeks before seedling, 210 kg/ha; Nitrocalcar fertilizer NAC 27 N (27% nitrogen) - 2 months after seedling, 100 kg/ha; granular urea 46.2-00-00 (46% nitrogen) - six months after seedling, 200 kg/ha), but the soil sampling has been done at seven months distance from the last fertilization and therefore considered with no residual effect at the sampling time. Probably there are other reasons to explain the low content of total nitrogen in both cultures of the silvoarable system, such as those revealed by several studies (Fortier et al., 2017) which showed that the leaf litter chemistry and decay rate may influence the N mineralization and nutrient release during decomposition, depending on the poplar genotype. The hybrid poplars require fertile soils to grow at their whole capacity (Boysen & Strobl, 1991; Rytter et al., 2011), but these trees can supply their demand through alternative mechanisms. For example, the nitrogen and potassium uptake can be supplied from the foliar leaching through internal cycling determined by seasonal leaf senescence (Fortier et al., 2020). This is a different situation as compared with other tree species, because previous studies (Rennenberg et al., 2010) showed that many forest ecosystems have been grew in soils with nitrogen limited availability, and they relied more on the internal cycling of the nitrogen than on external input. But, there was shown by other researches that poplars are very efficient in finding, due to their root expansive system, alternative nitrogen sources, like that resulted from the limitation of nitrogen leaching (Hermansen et al., 2017; Pugesgaard et al., 2015). However, several studies indicate as possible necessary the supplementary fertilization of soils planted with hybrid poplar for energy biomass, at least for that with short rotation cycle, both at the start and at the end of a cycle and even during the entire vegetation cycle (Savin et al., 2019).

The higher values of P and K in the rapeseed crop as compared to the poplar plantation have been revealed also by other studies on silvoarable poplar-based systems (Sirohi & Bangarwa, 2017), due to the poplar ability to protect the adjacent crops against phosphate leaching (Dimitriou & Mola-Yudego, 2017; Savin et al., 2019) or potassium loss (Sirohi & Bangarwa, 2017).

In order to find out possible relationships between the analyzed soil parameters, statistical tests have been processed, but generally, there were not found statistically significant (Paired-samples t-test, $p<0.01$, $p<0.02$) differences between the mean values of the soil factors across layers, excepting the pH of 0-10 cm versus pH of 10-20 cm, the humus of 0-10 cm and 10-20 cm versus the humus of 20-30 cm, and the total N of 0-10 cm versus the total N of 20-30 cm (Table 5).

The significant differences of the pH values within the soil layers 0-10 cm and 10-20 cm as compared with the other layers could be explained by the lithology of the substrate (Savin et al., 2019) or through the soil biome contribution in the topsoil due to the litter presence and no-till management in the poplar plantation. The significant differences of humus content across soil layers is associated with its decrease with the depth in the soil profile, because humus is formed through decomposition and humification of organic residues available at soil surface (Chatterjee et al., 2018). The significant differences regarding the contents of total nitrogen between soil depths are because the total nitrogen is heterogeneously distributed in soil and this depends on many factors, such as soil type, parent material, land use (Li et al., 2022).

The statistical processing of data (Kendall's and Spearman's Correlations) indicated statistically significant ($p<0.01$) correlations between several soil factors of the two components of the agroforestry ecosystem: between pH and K plant-available in the *Populus* spp. plantation and between humus and P plant-available in the rapeseed crop (Table 6).

Table 5. Differences between soil parameters (mean values) by depth of soil layer (Paired-samples t-test, $p<0.01$, $p<0.02$) in hybrid poplar plantation

Paired Samples Test						
Soil factors by depth of soil layer	Paired Differences		t	df	Significance	
	Mean	Standard Deviation			(p<0.01)	(p<0.05)
pH 0-10 cm - pH 10-20 cm	0.29333	0.15373	3.305	2	**0.040****	0.081
pH 0-10 cm - pH 20-30 cm	0.27667	0.39311	1.219	2	0.174	0.347
pH 10-20 cm - pH 20-30 cm	-0.01667	0.23965	-0.120	2	0.458	0.915
Humus 0-10 cm - Humus 10-20 cm	0.57333	0.45654	2.175	2	0.081	0.162
Humus 0-10 cm - Humus 20-30 cm	1.27000	0.41509	5.299	2	**0.017****	**0.034***
Humus 10-20 cm - Humus 20-30 cm	0.69667	0.23861	5.057	2	**0.018****	**0.037***
Total N 0-10 cm - Total N 20-30 cm	0.01333	0.00577	4.000	2	**0.029****	0.057
Total N 0-10 cm - Total N 10-20 cm	0.01667	0.01528	1.890	2	0.100	0.199
Total N 10-20 cm - Total N 20-30 cm	-0.00333	0.01155	-0.500	2	0.333	0.667
P plant available 0-10 cm - P plant available 10-20 cm	0.23667	0.98855	0.415	2	0.359	0.719
P plant available 0-10 cm - P plant available 20-30 cm	-1.26667	5.38778	-0.407	2	0.362	0.723
P plant available 10-20 cm - P plant available 20-30 cm	-1.50333	5.30119	-0.491	2	0.336	0.672
K plant available 0-10 cm - K plant available 10-20 cm	35.0000	35.15679	1.724	2	0.113	0.227
K plant available 0-10 cm - K plant available 20-30 cm	29.0000	26.00000	1.932	2	0.097	0.193
K plant available 10-20 cm - K plant available 20-30 cm	-6.00000	10.00000	-1.039	2	0.204	0.408

Table 6. Correlations ($p<0.01$, $p<0.05$) of the agroforestry ecosystem

Correlation factor 1	Correlation factor 2	Statistic correlation	Significance (p<0.01)
pH Hybrid poplar	K plant available Hybrid poplar	Kendall's tau_b Correlation Coefficient	1.000**
		Sig. (2-tailed)	0
		Spearman's rho Correlation Coefficient	1.000**
		Sig. (2-tailed)	0
Humus Rapeseed	P plant available Rapeseed	Kendall's tau_b Correlation Coefficient	1.000**
		Sig. (2-tailed)	0
		Spearman's rho Correlation Coefficient	1.000**
		Sig. (2-tailed)	0
**Correlation is significant at the 0.01 level (2-tailed).			

The positive correlation found between plant-available P and humus in the rapeseed soil could be explained through the findings of Spohn (2020) regarding the P contribution, both as organic and inorganic fractions, in the stabilization of the organic carbon in soil. The positive correlation between pH and plant-available K found in the poplar soil within this study is important because at low pH the K availability is low and could be explained as determined by the soil properties such as soil aggregates properties, adsorption capacity (Bronick & Lal, 2005; Linquist et al., 2022) or as microbiologically mediated (Zheng et al., 2022).

The results found within this study regarding the aimed soil factors of sustainability showed that the soil cultivated with rapeseed bordered by the poplar in the analyzed silvoarable ecosystem has greater values for pH, humus, plant-available P and plant-available K than the soil planted with hybrid poplar clones, but further investigations are required and completed with another indicators of sustainability previously analyzed in various ecosystems of the same studied zone (Timiș County), such as direct or indirect biological indicators of soil (Iordache, 2012; Iordache & Borza, 2012; Iordache, 2018).

CONCLUSIONS

The findings of this study show increases in several contents of soil nutrients (humus, plant-available P, plant-available K) for the rapeseed crop versus the soil planted with hybrid poplar within the silvoarable system and statistically significant ($p<0.01$) correlations between several soil factors of the two components of the silvoarable system: between pH and plant-available K in the *Populus* spp. plantation and between humus and plant-available P in the rapeseed crop.

This study emphasizes the favourable association for the rapeseed crop with hybrid poplars within a silvoarable system in terms of nutrient increase of the soil.

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