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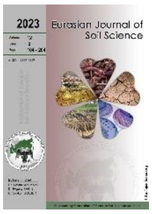

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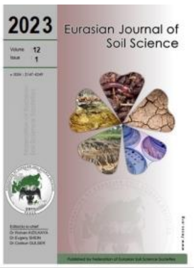

Yield response of rice (*Oryza sativa* L.) to elevated potassium applied under the irrigated ecosystem of Bangladesh

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Abstract

A field experiment was conducted at Bangladesh Agricultural University farm, Mymensingh, Bangladesh, during the Boro season, 2017 with six different K fertilizer rates: 0, 10, 20, 30, 40 and 50 kg ha^{-1} to determine the optimum rate of potassium (K) fertilization for the improved yield of a specific rice variety in the irrigated ecosystem under floodplain area. Compared with no K fertilizer, adding K increased the rice grain and straw yields significantly, with all other yield contributing components, except 1000-grain weight. The highest yield of grain (7.07 ton ha^{-1}) and straw (8.48 ton ha^{-1}) were recorded in recommended fertilizer dose (RFD) of NPS + 50kg K treatment, which were statistically identical with RFD of NPS + 40 kg K. Rice grain and straw yields due to the different treatments increased by 18.65% to 53.74% and 18.67% to 53.78%, respectively over control. K content and uptake through grain and straw were significantly influenced by applying different levels of K. These results specified that the use of 40 kg K ha^{-1} had better performance on the grain and straw yields. Therefore, we conclude that the application of 40 kg K ha^{-1} along with the RFD of NPS for BRRI dhan29 cultivation is the best option for higher yield in Old Brahmaputra Floodplain soil.

Keywords: Boro rice, floodplain, irrigated ecosystem, potassium, yield.

Introduction

Rice (*Oryza sativa* L.) is the principal grain crop for more than half of the world's population (IRRI, 2015). This population is rapidly approaching seven billion, and to meet their demand, global rice production needs to expand by 116 million tons by 2035 (Yamano et al., 2016). Asia has the largest share in rice production as the top rice consuming countries like China, India and Bangladesh are included in this region (Shahbandeh, 2021). Like many other countries, 'food security' in Bangladesh entirely depends on 'rice security'; hence, rice is the backbone of Bangladesh's agriculture (Brolley, 2015). According to BBS (2020), rice alone contributes around 4.5% of GDP.

For increasing rice yield, many techniques and approaches have been examined, such as fertilizer application (Hou et al., 2019), high yielding varieties (Yuan, 2017), irrigation management (Norton et al., 2017), weed control (Chauhan and Opeña, 2013) and frequent planting (Peng et al., 2015). By considering all of these above, soil fertilization is an affirmed strategy to enhance rice production where nitrogen (N), phosphorus (P) and potassium (K) are the most frequently applied nutrients. Compared to N and P, the K fertilizer is usually ignored by farmers as the grain yield response to K is lower than N and P (Li et al., 2014; Hou et al., 2019). However, K is essential for maintaining several physiological and metabolic activities of plants. It is crucial for

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controlling intracellular osmotic regulation, photosynthesis, and membrane protein transport as an enzymatic activator. Moreover, this encompasses a vital position in the transportation of carbohydrates in rice plants and stress resistance (Wang and Wu, 2013; Nieves-Cordones et al., 2019).

BRRI (Bangladesh Rice Research Institute) indicated that rice crops could remove 19.13–22.31 kg K to produce 1.0 tons of grain (Choudhury et al., 2013). However, this requirement can vary according to the variation of yield potential. For instance, rice crops can utilize about 103 kg K for a yield level of 7.0 ton ha^{-1} (FRG, 2012). The variations in K requirement with grain yield levels and cultivars emphasize K requirement's importance in calculating K balance and optimal K fertilizer doses for rice production practice. Furthermore, soil texture can also play a decisive role in selecting the proper fertilizer application rate. The positive response of rice to K was found up to 80 kg ha^{-1} in clay loam grey terrace soils of Bangladesh though there were seasonal and varietal differences in this regard (Naher et al., 2011). The general recommended K for haor areas, which are considered typical wetland ecosystems in Bangladesh, is about 35 kg ha^{-1} to cultivate rice with a yield potential of 7.5 ± 0.75 ton ha^{-1} (FRG, 2012). Low K dose cannot replenish soil K levels quickly to meet the maximum demand for rice crops. For this reason, rice plants can suffer from K deficiency, become more susceptible to biotic and abiotic stresses, and increase disease incidence (Zhang et al., 2019). Besides, several studies described the negative K balances in rice systems (Mohanty and Mandal, 1989; Miah et al., 2008). This negative balance and K mining from the soil are now generating an agitating situation in Bangladesh which varied between −100 and −225 kg ha^{-1} per year (Rijmpa and Islam, 2002). Additionally, researchers reported that the present K fertilizer dose is not enough to support a favourable K fertility status in the soils of Bangladesh (Islam and Muttaleb, 2016).

Therefore, to fight against these problems, there is no alternative other than the judicial application of K fertilizer for specific rice varieties. Quantifying the amount of K taken up from soil solution and soil solid portion may help take necessary measures to reduce the K mining from the soil. In this article, a field experiment was undertaken to determine the optimum rate of K on maximizing yield and yield contributing characters for a specific rice variety, BRRI dhan29.

Material and Methods

Site description

The experiment was conducted in 2017 at the Soil Science Field Laboratory of Bangladesh Agricultural University, Mymensingh, Bangladesh (Figure 1), during the Boro season (winter season). Mymensingh district falls under the Agro-Ecological Zone-9 of the Old Brahmaputra floodplain. This area belongs to the sub-tropical climate and is characterized by high temperatures accomplished by moderately high rainfall during the Kharif season (April to September) and low temperatures in the Rabi season (October to March). The land is moderately well-drained, and the land type is medium high. The famous high yielding Boro rice variety BRRI dhan29 was used as a test crop. It is a high yielding rice variety. The growth duration is around 155 to 160 days (BRRI, 2022). The physio-chemical characteristics of soil at the study site in Mymensingh, Bangladesh, are presented in Table 1.

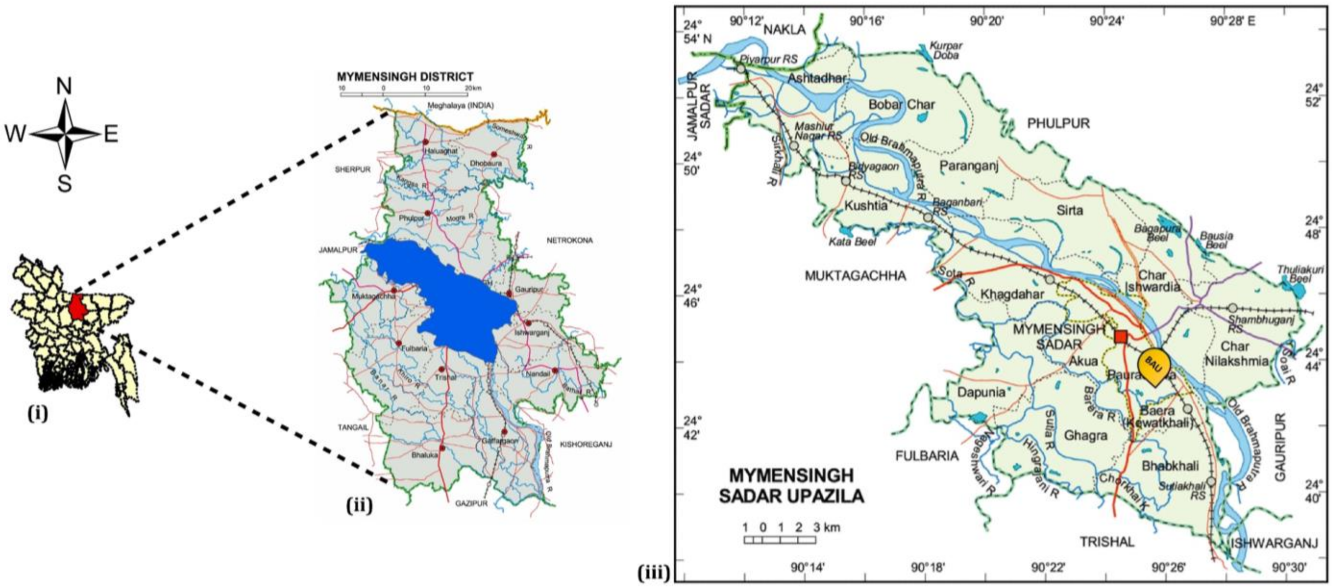

Figure 1. Map of the study site. (i) Location of study site in Bangladesh, (ii) Mymensingh district with study site and (iii) The specific area of our interest (ArcMap version 10.5)

Table 1. Physical and chemical properties of the soil sample

Properties	Methods	Values
Sand (%)		13.28
Silts (%)	Hydrometer method	74.00
Clay (%)		12.72
Textural class		Silt loam
pH	pH meter (glass electrode)	6.88
Organic matter (%)	Walkley and Black method	2.96
Total N (%)	Micro-Kjeldahl distillation method	0.18
Available P (ppm)	Olsen method	12.23
Exchangeable K (meq 100g^{-1} soil)	1 N NH_4OAc method	0.13
Available S (ppm)	0.01 M $Ca(H_2PO_4)_2$ extraction method	11.90
Cation Exchange Capacity, CEC (me 100g^{-1} soil)	Sodium Acetate method	12.70

Experimental design and treatments

Field preparation was started in January 2017. The experiment was placed in a Randomized Complete Block Design (RCBD). The entire experimental area was divided into four blocks with four replications to reduce soil heterogeneity, and each block was sub-divided into seven plots with raised bunds as per treatment. The unit plot size was 4m ×2.5m, and 0.5m bunds separated the plots. Therefore, the Seven treatment combinations were designated as

1. T1=Control (No fertilizer)
2. T2= RFD of NPS +K_0
3. T3=RFD of NPS +K_{10}
4. T4=RFD of NPS+K_{20}
5. T5=RFD of NPS+K_{30}
6. T6=RFD of NPS+K_{40}
7. T7=RFD of NPS+K_{50}

Recommended fertilizer dose (RFD) is N: P: S= 110: 20: 18 kg ha^{-1}

The nutrient source for nitrogen (N) was Urea, phosphorus (P) as Triple Super Phosphate (TSP), potassium (K) as Muriate of Potash (MoP) and sulphur (S) as Gypsum.

Crop management

The total dose of Triple Super Phosphate (TSP) and gypsum was applied during the final land preparation. Urea was applied in three equal splits: (a) one-third 15 days after transplanting, (b) second instalment after 30-35 days of transplanting and (c) the third instalment after 45-50 days after transplanting. Potassium was applied according to different treatments from Muriate of Potash (MoP). Forty days old seedlings were transplanted with a spacing of 20 cm x 20 cm. Three seedlings were transplanted on each hill. All intercultural operations were done to ensure and maintain the crop's expected growth. All the agronomical practices viz. irrigation, fertilizer application and intercultural operations were followed as recommended for rice crop in this specific area.

Data collection from the field

Five hills were randomly selected from each plot at the maturity stage to record the yield contributing characteristics like plant height, number of tillers hill^{-1}, panicle length, number of grains panicle^{-1}, and 1000-grain weight. The selected hills were collected before the crop harvest, and necessary information was documented accordingly. Grain and straw yields were recorded plot-wise at 14% moisture content and expressed as ton ha^{-1} on a fresh weight basis. In addition, grain and straw sub-samples were kept for chemical analysis.

Chemical analysis of grain and straw

The collected grain and straw sample from each plot was dried in an oven at 65^{0}C for about 24 hours, after which the grinding machine ground them. The prepared pieces were then put into paper bags and kept for analysis.

Plant samples of 0.5 g (grain and straw separately) were transferred into the digestion flask. Ten ml of the di-acid mixture (HNO_3 : $HClO_4$ = 2:1) were added into the flask. It was left for some time so that the temperature could slowly rise to 185^{0}C. Heating was stopped when the dense white fume of $HClO_4$ appeared. After cooling, the contents were taken into 50 ml volumetric flasks, and the volume was levelled with distilled water. K was determined from the extract by using a flame photometer. After chemical analysis of straw and grain samples, the nutrient uptake was calculated from the nutrient content and yield of rice crops by the following formula:

$$\text{Nutrient uptake} = \frac{\text{Nutrient content (\%)} \times \text{yield (kg per ha)}}{100}$$

Statistical analysis

Statistical analyses were performed using SPSS V. 25 software. The analysis of variance (ANOVA) for specific characters of rice crops with different nutrient concentrations and nutrient uptake was done following the F-test. Mean comparisons of the treatments were prepared by Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ level.

Results and Discussion

Fertilizer application has been inspected broadly by researchers to enhance crop production (Peng et al., 2010; Gu et al., 2017). This study described the necessity of optimum fertilization. Grain and straw yield with other yield contributing attributes are influenced significantly by the increasing K level.

Yield components

The first four yield contributing components (plant height, effective tillers hill^{-1}, panicle length and filled grains panicle^{-1}) were highly affected by the application of K fertilizer except for the fifth one, which was 1000-grain weight. There were significant interaction effects of K on all these parameters without the last one (Table 2).

According to field experiment results, the plant height varied from 74.25cm in the control treatment to 82.03 cm in the RFD of NPS+K_{50} treatment. However, the highest plant height recorded in NPS+K_{50} treatment was statistically similar to NPS+K_{30} and NPS+K_{40} treatments.

The K fertilizer application showed apparent effects for the following three components also. These three components represented the maximum outcome when treated with the RFD of NPS+K_{50} (effective tillers hill^{-1}, panicle length, and filled grains panicle^{-1} were 12.00, 23.62 cm, and 103.5 for this treatment implementation, respectively). Interestingly, these three parameters that exhibited the highest results during the RFD of NPS+K_{50} application was statistically identical to those found in the treatments NPS+K_{40}, NPS+K_{30}, and NPS+K_{20}.

There was an insignificant effect of different K levels on 1000-grain weight of BBRI dhan29. The grain weight varied from 21.65 to 22.8 g (Table 2). The highest 1000-grain weight (22.8 g) was found in treatment T7, and the lowest (21.65 g) value was obtained in treatment T1.

Table 2. Effect of different treatments of K on the yield contributing characters of BRRI dhan29

Treatments	Plant height (cm)	Effective Tillers Hill^{-1}	Panicle Length (cm)	Filled grains panicle^{-1}	1000-grain weight (g)
Control	74.25e	8.00f	20.51e	75.50e	21.65
RFD of NPS+K_0	77.75d	9.00e	21.92d	81.43d	21.97
RFD of NPS+K_{10}	77.93bc	9.50cd	22.73bc	82.68bc	22.02
RFD of NPS+K_{20}	78.03ab	10.00abc	22.88ab	89.87ab	22.12
RFD of NPS+K_{30}	78.43ab	10.75ab	23.05ab	95.12ab	22.30
RFD of NPS+K_{40}	79.25ab	11.75a	23.23a	101.87a	22.72
RFD of NPS+K_{50}	82.03a	12.00a	23.62a	103.50a	22.80
SE (±)	0.86	0.55	0.39	4.04	0.15
CV (%)	2.93	14.36	4.63	11.88	1.86

Figures in a column having common letter(s) do not differ significantly at 5% level of significance. CV and SE denote coefficient of variation and stand error of means, respectively.

Our analysis of yield contributing components indicated that the addition of K fertilizer improved the overall status for all only except the 1000-grain weight. K application at a level higher than the recommended dose consistently raised the plant height. The results also revealed that the RFD of NPS+K_{50} application produced the peak plant height, and this treatment was the best among all other treatments (Table 2). Bahmaniar et al. (2007) found that plant height increased significantly due to K application. The same outcome was also recorded by Mukherjee and Sen (2005) and Biswas et al. (2001) as K encompasses major role in promoting plant stem elongation (Marschner, 1995). Likewise, the effective tillers hill^{-1}, panicle length, and the number of filled grains panicle^{-1} also increased with the increasing rate of K fertilizer. Our findings agree with other researchers who demonstrated that increasing K application positively impacts the improvement of these specific yield contributing parameters (Krishnappa et al., 1990; Mitra et al., 2001; Bahmaniar et al., 2007). Asif et al. (2007) reported that K application as full dose can enhance the flowering, grain number and early physiological maturity in plants. In accordance with Zhang et al. (2019) and Cheema et al. (2012), the use of non-structural carbohydrates in the vegetative part of plants increase when an adequate K supply is confirmed. This may improve the leaf area index and natural buffering capacity of rice for grain filling, which can eventually contribute to the final yield. However, there was no significant effect on the 1000-grain weight of BRRI dhan29 by applying different levels of K fertilizer. Bahmaniar et al. (2007) also reported the identical consequence.

Grain and straw yield

The grain and straw yields of rice are displayed in Table 3. It represents that both parameters were significantly improved by applying K fertilizer. The highest grain yield response of BRRI dhan29 rice variety (7.07 ton ha^{-1}) was obtained with the RFD of NPS+K_{50} treatment which was more than double the control (3.27 ton ha^{-1}). Treatments T6 (RFD of NPS+K_{40}) and T5 (RFD of NPS+K_{30}) with grain yield of 6.79 and 5.70 ton ha^{-1}, respectively, demonstrated statistically similar results with the T7 (RFD of NPS+K_{50}), indicating no different effects among these three treatments. Furthermore, the increase in grain yield over control ranged from 18.65 to 53.74%, where the highest percentage (53.74%) of increased grain yield over the control was recorded in treatment T7, and the lowest rate was observed in treatment T2.

The straw yield of rice also followed the same theme as grain yield. Plots treated with RFD of NPS+K_{50} showed maximum straw yield, 8.48 ton ha^{-1}, which was statistically similar to those plots treated with NPS+K_{40} and NPS+K_{30} treatment. The treatment T7, i.e. NPS+K_{50}, revealed the best percentage of increased straw yield over control and the least was found in the no application of K fertilizer (T2).

Table 3. Effect of different treatments of K on grain and straw yields of BRRIdhan29

Treatments	Grain yield (ton ha^{-1})	%Grain yield increased over control	Straw yield (ton ha^{-1})	% Straw yield Increased over control
Control	3.27e	-	3.92f	-
RFD of NPS+K_0	4.02d	18.65	4.82e	18.67
RFD of NPS+K_{10}	4.32c	24.30	5.18cd	24.32
RFD of NPS+K_{20}	4.97bc	34.20	6.21c	36.87
RFD of NPS+K_{30}	5.70ab	42.63	7.12ab	44.94
RFD of NPS+K_{40}	6.79a	51.84	8.14a	51.85
RFD of NPS+K_{50}	7.07a	53.74	8.48a	53.78
SE (±)	0.53	-	0.65	-
CV (%)	27.6	-	27.57	-

Figures in a column having common letter(s) do not differ significantly at 5% levels of significance. CV: Coefficient of variation; SE (±): Standard error of means.

In a study, Ye et al. (2020) evaluated that the rice yield has high positive feedback on the K fertilizer application. This statement strongly supports our findings. The increasing rate of applied K fertilizer increased the grain yield of BRRI dhan29. The highest grain yield was recorded in T7 (RFD of NPS+K_{50}) while using the different fertilizers as a recommended dose. K is an essential element for the photosynthesis process with carbohydrate translocation and metabolism that can ultimately boost grain production (Pettigrew, 2008; Zorb et al., 2014; Lu et al., 2016). The increased grain yield might also be obtained because the K can provide resistance to many stress conditions and reduce grain sterility (Ma et al., 2019). The higher K dose also exerted a pronounced effect in producing a higher straw yield of the BRRI dhan29 variety. In our study, like grain yield, the K application with 50 kg ha^{-1} dose also brought out the highest straw yield. This might be because K increases rice strength, prevents lodging, and increases resistance to pest, which ultimately results in a higher yield of straw. Islam and Muttaleb (2016) in their field study observed that K enhanced rice crop grain and straw yield. They stated that K assists in improving the nitrogen uptake and its utilization, which can help in enhancing the rice yield. A similar result was also reported by Saha et al. (2007) and Saleque et al. (1998). Our study represented that the selected yield contributing factors significantly influenced and promoted rice grain yield. The higher K rate may be improved the overall quality of these factors, which finally enhances the grain yield (Atapattu et al., 2018).

Potassium content accumulation and uptake through rice grain and straw

The potassium (K) content that was available in the rice grain and straw after harvesting and K utilization by them were analyzed in this study. Both of these parameters were influenced by the K application (Table 4).

The K content in rice grain and straw depended on the K rate. The maximum K content was recorded in T7 (RFD of NPS+K_{50}) application for both grain and straw, which was 0.269% and 1.374%, respectively. However, there were no statistically significant differences in K content among T7, T6, T5 and T4 treatment applications.

It was found that compared with the control and K0 treatments, the K addition progressively boosted the K uptake by grain and straw. The K uptake by grain and straw varied from 4.77 to 19.01 kg ha^{-1} and 43.51 to

116.51 kg ha^{-1}, respectively. The highest K uptake was recorded from the rice grain and straw grown with 50 kg of K treatment application (T7). Here, Table 4 represents that treatment T7 and T6 (NPS with 50kg K and 40kg K, respectively) are statistically equivalent during K uptake through grain and straw of the selected rice variety. The total K uptake also demonstrated the same pattern.

Table 4. Effect of different treatments on K content and uptake by grain and straw of BRRI dhan29

Treatments	%K Content		K Uptake (kg ha^{-1})		Total K Uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
T1: control	0.146d	1.110e	4.77g	43.51e	48.28e
T2: RFD of NPS+K_0	0.253c	1.363d	10.17f	65.69d	75.86d
T3: RFD of NPS+K_{10}	0.256b	1.366bc	11.05de	70.75c	81.80c
T4: RFD of NPS+K_{20}	0.259a	1.368ab	12.87cd	84.95b	97.82b
T5: RFD of NPS+K_{30}	0.264a	1.371ab	15.04bc	97.61b	112.65b
T6 : RFD of NPS+K_{40}	0.267a	1.373a	18.13ab	111.87a	130.00a
T7: RFD of NPS+K_{50}	0.269a	1.374a	19.01a	116.51a	135.52a
SE(±)	0.016	0.037	1.86	9.96	11.82
CV (%)	17.95	7.35	37.94	31.22	32.10

Figures in a column having common letter(s) do not differ significantly at 5% levels of significance. CV: Coefficient of variation; SE (±): Standard error of means.

K content and uptake in rice grain and straw were significantly influenced due to different levels of K application. With the increase of K application, the k concentration and uptake in rice grain and straw also raised significantly (Table 4). Saleque et al. (1998) also mentioned that the K content, and K uptake can enhance in rice with increasing K fertilization. The related result was also demonstrated by Ahsan et al. (1997). Our results exhibited that the K content and uptake were always higher in straw than in grain.

Conclusion

Grain and straw yield, K content and uptake, and all the other yield contributing properties of the BRRI dhan29 rice variety were improved by the K application. The highest grain yield of 7.07 ton ha^{-1} and straw yield of 8.48 ton ha^{-1} of rice were recorded in RFD of NPS+ 50 kg K ha^{-1}, which were statistically identical to those observed in treatment T6 (6.79 ton ha^{-1} and 8.14 ton ha^{-1} for grain and straw, respectively) having 40 kg ha^{-1} potassium application. From the result, it can be decided that 40 kg potassium application per ha and a recommended dose of NPS are suitable for getting a maximum yield of BRRI dhan29 rice at Old Brahmaputra Floodplain Soil. As the K fertilizer application rate depends on soil fertility status, crop variety and yield, substantial research in this field is needed to prescribe appropriate K rates to farmers of different regions.

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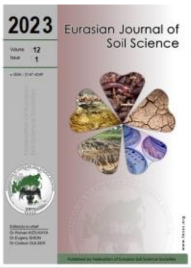

Optimum wheat productivity under integrated plant nutrient management is associated with improved root system and high nutrient efficiency

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Abstract

Depleting soil fertility and low fertilizer efficiency in alkaline calcareous soils are serious issues worldwide creating an immediate threat to environment and food security. Integrated nutrient management (INM) can be a promising eco-friendly strategy for improving crop performance and resource efficiency to resolve these concerns. A field study was conducted to investigate the integrated effect of organic sources [farm yard manure (FYM) @ 10 tons ha^{-1} and press mud (PM) @ 5 tons ha^{-1}] along with various NPK rates [100, 75, 50% recommended dose of fertilizer (RDF)] on root system, nutrient efficiency, and yield of wheat cultivar Kiran-95. Longest roots were measured in FYM + RDF$_{50}$ while highest surface area and number of root tips were recorded in PM + RDF$_{50}$ than RDF alone. However, maximum root volume and average root diameter was observed in PM + RDF$_{100}$ and PM + RDF$_{75}$, respectively compared with RDF only. PM + RDF$_{100}$ considerably enhanced grain yield and related traits i.e., spike length, tillers count m^{-2} and 100-grain weight as compared to RDF only. Integration of PM and 100% RDF showed higher NPK uptake, than RDF alone. Recovery efficiency (RE) of NPK was calculated higher at lower fertilizer rates and vice versa. The sole application of RDF$_{100}$ showed least RE of NPK whilst PM + RDF$_{50}$ revealed higher RE of NPK. The results suggested that INM could be a sustainable approach to enhance wheat productivity and nutrient efficiency in alkaline calcareous soils. In addition, PM along with RDF$_{100}$ NPK fertilizers proved superior in improving root traits and nutrient accumulation thereby increasing wheat grain yield.

Keywords: Farm yard manure, nutrient substitution, press mud, root traits, wheat.

Introduction

Soil is a non-renewable natural resource, facing serious hazards of degradation due to unsustainable land uses and management practices worldwide. The loss in soil fertility due to continuous nutrient mining by crops without adequate replenishment is creating an immediate threat to environment and food security (Ahmad et al., 2007). Wheat (*Triticum aestivum* L.) is a leading food grain crop of Pakistan, contributing about 1.7% of the country's GDP and 8.7% of value addition in agriculture. During 2020-21, area under wheat crop was 9.178 million hectare with annual production of 27.293 million tons while average yield stood at 2.97 tons per hectare (GOP, 2021). This current yield per hectare of wheat is very low than the potential yield. There are multiple soil related constraints behind low yield including low organic matter, high pH, calcareousness, nutrient depletion and less use of organic nutrient sources (Akhtar et al., 2007). Low soil organic matter (< 1%) and associated nutrient supply is among the leading yield limiting factors in intensive cereal based cropping systems of arid and semi-arid regions worldwide (Mulvaney et al., 2009). Moreover, indiscriminate use of chemical fertilizers deteriorates soil structure, pollutes ground water and increases nitrate

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concentration (Zhang et al., 2010). Although, the use of mineral fertilizers cannot be over-looked but due to their rising costs and environmental concerns, there is a need to supplement them with available organic resources (Phullan et al., 2017). Additionally, soil fertility status can be restored, maintained and/or improved with the integrative use of organic and mineral nutritional sources (Akhtar et al., 2007).

Prior to green revolution, farmers usually replenished their soils for plant nutrients by adding different organic wastes. Synthetic fertilizers enabled farmers to get higher yields only with these fertilizers, thereby reducing the use of organic materials drastically (Ahmad et al., 2007). Use of mineral fertilizers alone in intensive cropping systems creates infertility and unfavorable soil physical, chemical and biological conditions for optimum plant growth (Speir et al., 2004). The high costs of chemical fertilizers and soil degradation concerns have forced people to reconsider the organic sources in agriculture again. The gradually deteriorating soil health can be mitigated by use of organic sources (Jilani et al., 2007). Inclusion of these materials has been advocated to improve soil organic matter, soil structure, water infiltration, water holding capacity, aeration and soil granulation (Ibrahim et al., 2012). Optimum use of organic materials also encourages biological activities in soil. Combined application of organic and chemical fertilizers influence positively on microbial biomass and hence soil health (Dutta et al., 2003). However, type and quality of organic materials and application method are crucial for influencing soil characteristics and nutrient recycling (Ahmad et al., 2007; Chaudhry et al., 2013). According to Pang and Letey (2000), different organic sources have different decay rates, so the rate of nutrient mineralization for various sources is not matched with the rate of nutrient uptake by different crops.

During the past few decades, cultivation of high yielding genotypes in intensive agriculture and imbalanced use of chemical fertilizers has negatively influenced soil fertility in many sub-optimal agro-ecosystems around the globe (Speir et al., 2004). Integrated nutrient management (INM) is of utmost significance for improving soil fertility, biological properties, soil carbon pools and sustaining crop productivity of intensive cropping systems (Brady and Weil, 2008; Kumari et al., 2011). The prime objective of this concept is to increase crop yield, reduce cost of production and improve soil health (Singh et al., 2008). Different components of this approach includes: recycling of crop residues, use of organic manures, inclusion of soil fertility restoring crop, cultivation of efficient genotypes, utilization of biological agents, and balanced use of fertilizers (Wu and Ma, 2015). Adoption of INM concept is imperative to enhance input use efficiency, soil health and crop production in order to ensure global food security. This is the best approach for better utilization of organic nutrient sources to produce crops with less expenditure (Swarup, 2010). It optimizes all aspects of nutrient cycling intended to synchronize nutrient demand by the plants and its release into the soil (Zhang et al., 2012). It also minimizes land degradation and enhances farm productivity by improving soil physical, chemical, biological and hydrological properties (Saikia et al., 2015)..

Cattle's farm yard manure (FYM) and press mud (PM) from sugar industry are indigenous nutrient sources for crop production. The FYM is a cheap and easily available organic source which supplies macro and micronutrients, besides improving soil health (Sabah et al., 2014). The PM is a solid by-product of sugar industry which is about 3% from total quantity of cane crushed and is a rich source of organic carbon, NPK and micronutrients (Rakkiyappan et al., 2001). In Pakistan, it has been estimated that about 1.5 million tons of nutrients are available from FYM, while sugar industry is producing about 1.2 million tons of PM every year (Soomro et al., 2013). Several researchers have reported that long-term and balanced application of chemical fertilizers and organic sources can improve soil health, crop productivity, and nutrient use efficiency than any of these applied alone (Shah et al., 2009; Antil et al., 2011; Sabah et al., 2014; Ganaie et al., 2015). The present field study was therefore, planned to investigate the integrative response of FYM and PM along with various rates of NPK fertilizer on root system architecture, nutrient use efficiency and grain yield of wheat crop in alkaline calcareous soil.

Material and Methods

Site description

Experiment was conducted during Rabi, 2018-19 at the research area (Latitude 25º 24' 47" North and Longitude 68º 31' 07" East) of Nuclear Institute of Agriculture (NIA), Tandojam – Pakistan. The climate of the study area is arid with average annual precipitation of 136 mm. During the study period, the average daily maximum and minimum temperatures were 28.5 and 11.8 °C respectively, while average sunshine was 8.3 hours day^{-1}, average relative humidity was 56.1% and average evaporation was 4.4 mm day^{-1}. The maximum total rainfall (28.0 mm) was recorded in the month of January, 2019 (Figure 1). The soil of the experimental site was silt loam in texture, slightly alkaline in soil reaction, deficient in organic matter, total nitrogen and available phosphorus, while adequate in available potassium. Detailed soil physico-chemical properties of the experimental site (down to 0 - 6"and 7 - 12" depth) are given in Table 1.

Table 1. Physico-chemical properties of experimental site (down to 0 - 6" and 7 - 12" depths) and nutrient composition of organic amendments (FYM and PM) used in the study

Parameters	Units	Soil		Organic amendments	
		0 – 6″	7 – 12″	FYM	PM
Sand	%	8.10	10.60	-	-
Silt	%	73.58	71.70	-	-
Clay	%	18.32	17.70	-	-
Textural class	-	Silt loam	Silt loam	-	-
pH_s	-	7.90	7.80	-	-
EC_e	dS m^{-1}	4.18	2.14	-	-
Organic matter	%	0.80	0.72	-	-
$CaCO_3$ contents	%	5.92	5.95	-	-
Sodium (Na)	mg g^{-1}	35.65	23.00	-	-
Chlorides (Cl)	mg g^{-1}	0.14	0.27	-	-
Nitrogen (N)	mg g^{-1}	0.53	0.36	7.00	12.0
Phosphorus (P)	mg g^{-1}	0.0031	0.0011	2.30	1.50
Potassium (K)	mg g^{-1}	0.158	0.124	26.0	62.0

FYM = farm yard manure; PM = press mud; pH_s = pH of soil saturated paste; EC_e = electric conductivity of saturated paste extract

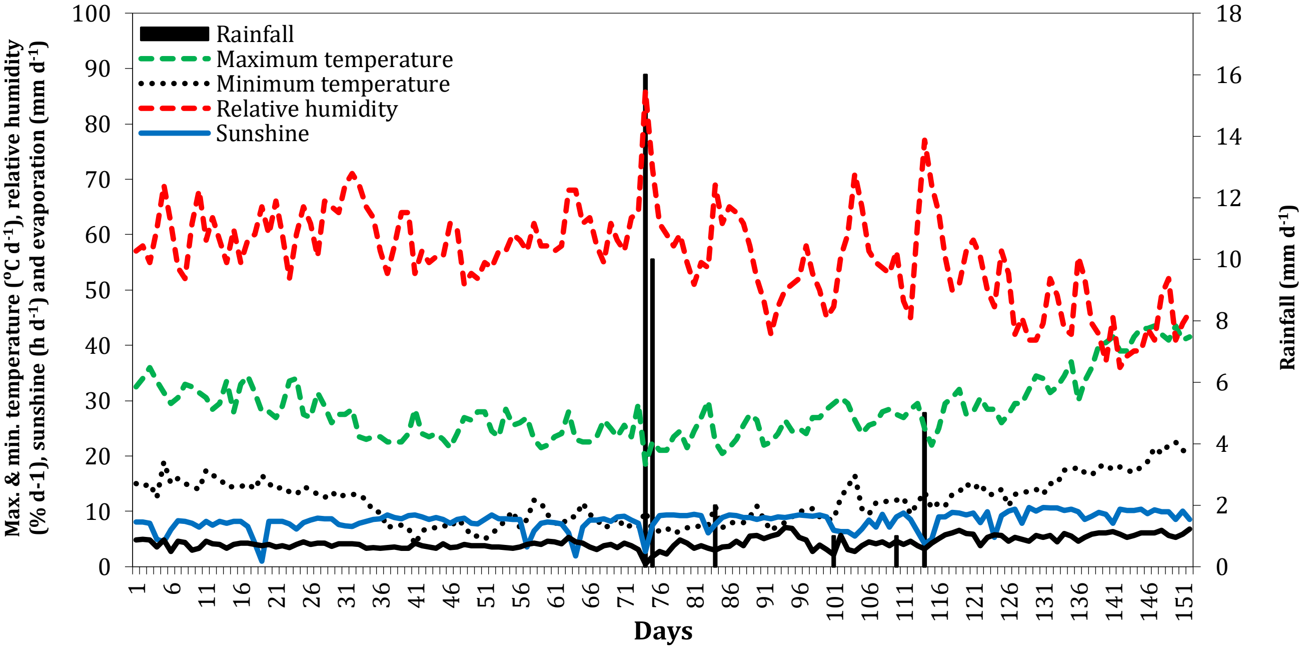

Figure 1. Daily maximum and minimum temperatures (ºC day^{-1}), relative humidity (% day^{-1}), sunshine (hours day^{-1}), evaporation (mm day^{-1}), and rainfall (mm day^{-1}) during the whole growing period of wheat crop

Experimental details

A field experiment was conducted to investigate the integrated effect of organic amendments i.e., farm yard manure (FYM) and press mud (PM) along with different rates of NPK fertilizer i.e., 100, 75, and 50% recommended dose of fertilizer (RDF) on yield, nutrient use efficiency and root morphology of wheat crop. The FYM and PM were applied at the rate of 10 and 5 tons ha^{-1} respectively, while RDF was used at the rate of 120-90-60 kg N-P-K ha^{-1}. A randomized complete block design was employed with three replications and ten treatments (control, RDF, FYM, FYM + RDF_{100}, FYM + RDF_{75}, FYM + RDF_{50}, PM, PM + RDF_{100}, PM + RDF_{75}, and PM + RDF_{50}). Detail of treatments used in experiment is described in Table 2. Seed of wheat cultivar ‘Kiran-95’ was obtained from Plant Breeding and Genetics Division of NIA, Tandojam – Pakistan. Sowing of wheat crop was done in individual plots of size 5 m × 5 m using single row hand drill by keeping inter-row spacing of 30 cm and seed rate of 125 kg ha^{-1}. Required amount of phosphorus and potassium according to treatment plan was applied at sowing, while nitrogen was applied in three equivalent splits i.e., at sowing, tillering, and booting stage. All other agronomic and crop protection measures i.e., irrigation, weeding, etc. were adapted uniformly to all plots. At maturity, the crop was harvested, threshed mechanically and data regarding yield and associated traits were recorded.

Soil analysis

For determining soil physico-chemical properties of experimental soil, five samples were randomly collected prior to crop sowing. A composite sample was air-dried and grounded to pass through a 2 mm sieve. Soil texture was determined using hydrometer method by performing mechanical analysis of soil separates (sand, silt, and clay) in which soil is dispersed with sodium hexametaphosphate solution (Bouyoucos, 1962). Soil reaction (pH) and electrical conductivity (EC) were determined using soil saturated paste following Anderson and Ingram (1993). Organic matter was quantified by chromic acid digestion according to Walkley-Black method (Nelson and Sommers, 1982). Calcium carbonate, sodium and chloride contents in soil were estimated according to Estefan et al. (2013). Kjeldahl nitrogen was determined following Jackson (1962). While Phosphorus and potassium were estimated using ammonium bicarbonate-diethylene triamine penta-acetic acid (AB-DTPA) as extracting solution (Soltanpour and Workman, 1979).

Table 2. Detail of treatments used in individual plot (n = 3)

	Treatments	Abbreviation	N	P_2O_5	K_2O
T_1	Control	Control	-	-	-
T_2	RDF (100%)	RDF_{100}	120	90	60
T_3	FYM (10 t ha^{-1})	FYM	-	-	-
T_4	FYM (10 t ha^{-1}) + RDF (100%)	FYM + RDF_{100}	120	90	60
T_5	FYM (10 t ha^{-1}) + RDF (75%)	FYM + RDF_{75}	90	67.5	45
T_6	FYM (10 t ha^{-1}) + RDF (50%)	FYM + RDF_{50}	60	45	30
T_7	PM (5 t ha^{-1})	PM	-	-	-
T_8	PM (5 t ha^{-1}) + RDF (100%)	PM + RDF_{100}	120	90	60
T_9	PM (5 t ha^{-1}) + RDF (75%)	PM + RDF_{75}	90	67.5	45
T_{10}	PM (5 t ha^{-1}) + RDF (50%)	PM + RDF_{50}	60	45	30

RDF = recommended dose of fertilizer; FYM = farm yard manure; PM = press mud ; Fertilizer (N, P, K) levels are based on kg ha^{-1}

Characterization of root system architecture

At anthesis, three plants were selected from individual treatment in order to characterize root system architecture. The selected plants were carefully removed from field with soil to ensure maximum protection of the plant root systems. Shoots were separated from roots at the crown level and the soil was gently washed away by slow agitation in a water tank. After washing the adhering soil, root system was gently blotted with absorbent paper. They were then scanned to determine following root parameters i.e., root length, surface area, number of root tips, average root diameter and root volume using root scanner (Epson Professional Scanner), and the images were analyzed using WinRHIZO™ Pro software (Regent Instruments Inc., Canada).

Plant analysis

Plant samples (grain and straw) were dried in a forced air-driven oven at 70 °C for 72 hours. Dry samples were grinded to pass through a 0.42 mm screen using a Wiley's mill. Plant samples were analyzed for total N concentration following modified Kjeldahl method using a fully automated distillation unit (2200 Kjeltec, FOSS, UK). Samples (0.3 g each) were wet digested using 10 mL of di-acid digestion mixture [(HNO_3:$HClO_4$ (5:1, *v/v*)]. Total P concentration in samples was estimated according to procedure as described by Estefan et al. (2013) at 470 nm wavelength using a double beam spectrophotometer (U-2900UV/VIS, Hitachi, Japan). While total K concentration was determined using flame photometer (Corning 400, UK).

Calculation methods

Nutrient uptake (NU), and nutrient efficiency relations i.e., recovery efficiency (RE), agronomic efficiency (AE) were calculated following Pan et al. (2017).

$$\mathrm{NU\ (kg\ ha^{-1})} = \frac{\mathrm{N\ concentration\ (\%)} \times \mathrm{Grain\ or\ straw\ yield\ (kg\ ha^{-1})}}{100}$$

$$\mathrm{RE\ (\%)} = \frac{(\mathrm{TNU_F} - \mathrm{TNU_{CK}})}{\mathrm{F_N}} \times 100 = \frac{\Delta \mathrm{TNU}}{\mathrm{F_N}} \times 100$$

$$\mathrm{AE\ (kg\ kg^{-1})} = \frac{(\mathrm{GY_F} - \mathrm{GY_{CK}})}{\mathrm{F_N}} = \frac{\Delta \mathrm{GY}}{\mathrm{F_N}}$$

Where TNU_F and TNU_{CK} shows total nutrient uptake (kg ha^{-1}) from fertilized and control plots, respectively; GY_F and GY_{CK} is grain yield (kg ha^{-1}) of fertilized and control plots, respectively; and F_N is the amount of nutrient applied (kg ha^{-1}).

Statistical analysis

The generated data was subjected to statistical analysis using computer based software STATISTIX 8.1 (Analytical Software, Inc., Tallahassee, FL, USA) to evaluate the response of integrated plant nutrient management on root system, yield and nutrient efficiency of wheat crop. All data reported in this manuscript are the means of three replicates and presented with standard errors. Treatment means showing significant differences among each other were identified through least significant difference test at 5% probability level. While graphical presentation of the data was performed using Microsoft Excel (Redmond, WA, USA).

Results

Variation in root system architecture of wheat under INM

The data pertaining to various root traits i.e., root length (RL), surface area (SA), number of root tips (NRT), average root diameter (ARD), and root volume(RV) of wheat plants are depicted in Figure 2. Results indicated that integration of chemical fertilizers with organic sources i.e., farm yard manure (FYM) and/or press mud (PM) significantly improved the studied root traits. The magnitude of RL varied from 190.7 cm in control to 494.3 cm in FYM + RDF_{50} treatment. However the treatments FYM + RDF_{50} and PM + RDF_{50} showed statistically identical results for RL. Overall, 14% higher RL was recorded with the integration of PM as compared to FYM. Root SA increased at lower rates of NPK fertilizer, irrespective of amendments. Highest root SA (96.9 cm^2) was measured in treatment PM + RDF_{50} followed by FYM + RDF_{50} (90.2 cm^2) while minimum was recorded in control (27.8 cm^2). The NRT per plant varied with changing NPK rates along with organic interventions. The NRT increased from 598 in control treatment to 928 in PM + RDF_{50} followed by PM + RDF_{75} (900) and FYM + RDF_{50} (879). Wheat plants showed differential response for ARD to applied fertilizer with or without PM and/or FYM. The control treatment exhibited least ARD (0.50 mm), which escalated to 0.54 and 0.66 mm in response to FYM and PM, respectively. Averaged across amendments, PM resulted in 8% higher ARD than FYM. The maximum RV (1.35 cm^3) was noticed in PM + RDF_{100} showing statistical similarity with FYM + RDF_{100} (1.32 cm^3). However, least RV (0.43 cm^3) was recorded in control plots.

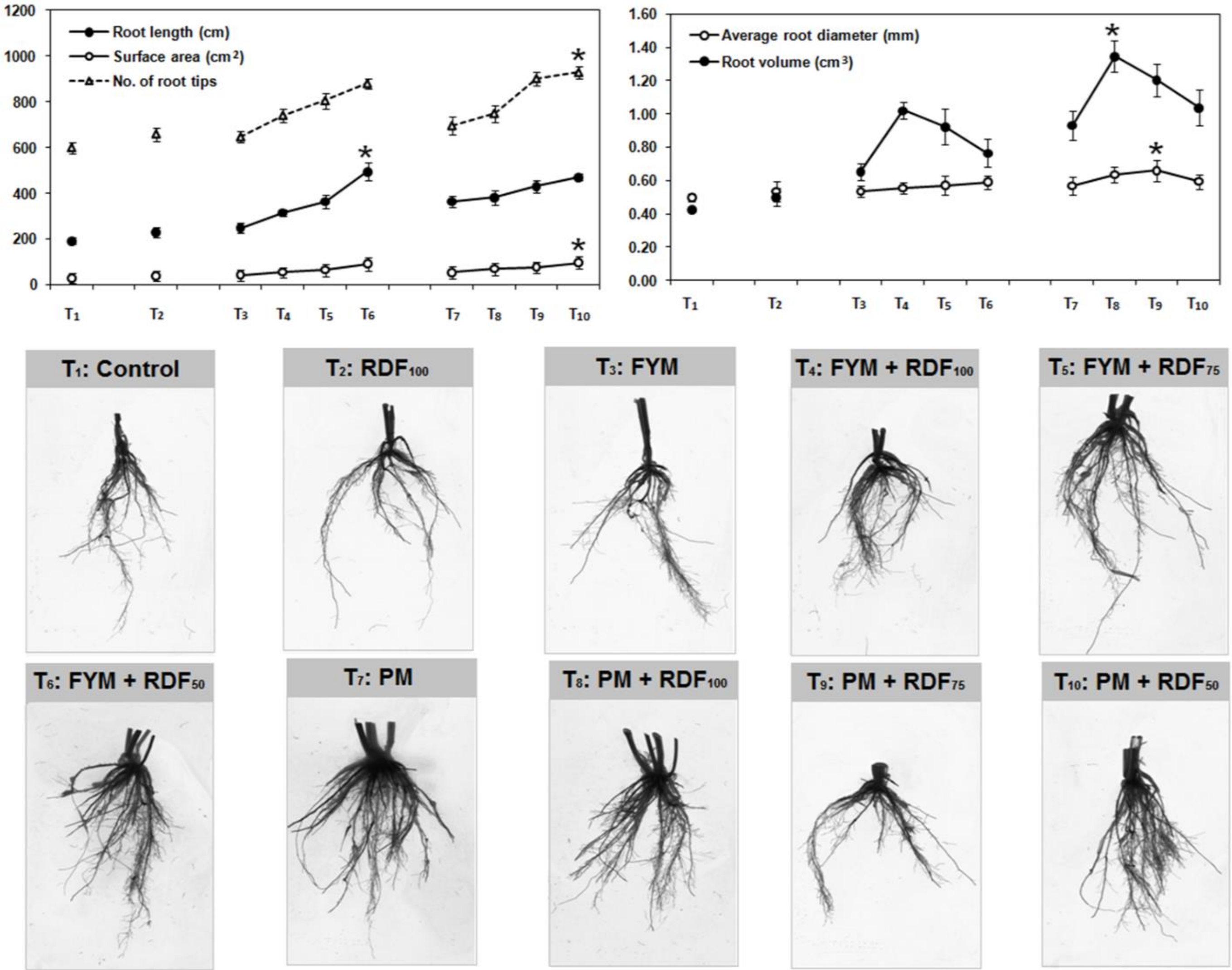

Figure 2. Variation in different components of root system architecture (i.e. root length, surface area, No. of root tips, average root diameter, and root volume) of wheat in response to integrated plant nutrient management. Treatment details are given in Table 2. Each plotted point is the mean ± SE of three replicates. Significant highest value for each root trait is indicated by * (LSD test, $P \leq 0.05$)

Yield and associated traits of wheat in response to INM

Yield and associated traits of wheat crop varied significantly ($P \leq 0.05$) in response to integrated management of inorganic and organic intrusions. The data regarding yield associated traits i.e., plant height, number of tillers m^{-2}, spike length, and 100-grain weight are presented in table 3. Results revealed that different treatments contributed effectively in enhancing yield of wheat crop. Moreover, integrated effect of PM was more pronounced than FYM with respect to traits relevant to yield. Integration of organic amendments and chemical fertilizers increased plant height of wheat plants as compared to sole addition of chemical fertilizers. Control plots showed least plant height (85.7 cm) while the treatment PM + RDF$_{100}$ produced highest plant height (100.3 cm).Variations among different treatments for number of tillers m^{-2} were found significantly. The data indicated that treatment PM + RDF$_{100}$ produced highest number of tillers m^{-2} (576) followed by FYM + RDF$_{100}$ (543) while minimum number of tillers m^{-2} were recorded in control (253). Treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ remained at par to each other (493 vs. 485). Spike length increased but remained at par with corresponding increase in fertilizer rates with either organic source. Control plots revealed spike length of 8.1 cm which enhanced to 10.3 cm with the RDF$_{100}$ while maximum spike length (10.7 cm) was recorded in PM + RDF$_{100}$ treatment. Likewise minimum 100-grain weight (2.61 g) was observed in control treatment that was increased to maximum (4.77 g) in PM + RDF$_{100}$ treatment. While treatments FYM + RDF$_{100}$ and PM + RDF$_{75}$ remained non-significant with each other (4.44 vs. 4.55 g).

Table 3. Yield and associated traits of wheat crop in response to integrated plant nutrient management

Treatments	Plant height (cm)	No. of tillers m^{-2}	Spike length (cm)	100-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Control	85.7 c	253 f	8.1 d	2.61 f	2.7 e	4.9 f
RDF$_{100}$	97.9 a	433 c-e	10.3 ab	4.04 d	4.9 b	7.1 ab
FYM	91.4 b	375 e	9.1 c	3.47 e	3.2 d	5.7 d-f
FYM + RDF$_{100}$	98.1 a	543 ab	10.4 ab	4.44 bc	5.3 a	7.4 a
FYM + RDF$_{75}$	97.1 a	485 b-d	10.4 ab	4.33 c	4.7 b	6.4 b-d
FYM + RDF$_{50}$	96.6 a	440 c-e	10.2 ab	4.27 c	4.0 c	6.0 c-e
PM	92.0 b	402 de	9.8 bc	3.63 e	3.3 d	5.3 ef
PM + RDF$_{100}$	100.3 a	576 a	10.7 a	4.77 a	5.6 a	7.8 a
PM + RDF$_{75}$	99.7 a	493 a-c	10.5 ab	4.55 b	4.8 b	6.7 bc
PM + RDF$_{50}$	97.3 a	460 b-e	10.1 ab	4.32 c	4.3 c	6.1 cd
LSD 0.05	3.87	88.5	0.86	0.21	0.34	0.78

Treatment details are given in Table 2. Treatment means not sharing similar letter(s) in the same column differ significantly from each other (LSD test, $P \leq 0.05$). Values are means of three replications (n = 3)

Wheat yield increased significantly in response to organic sources alone and/or in conjunction with chemical fertilizers (Table 3). In this regard, yield response of PM was observed higher when combined with chemical fertilizers thereby proving superior to all other treatments. Maximum grain yield (5.6 t ha^{-1}) was recorded in PM + RDF$_{100}$ treatment that showed statistical similarity to treatment FYM + RDF$_{100}$ (5.3 t ha^{-1}). Control produced grain yield of 2.7 t ha^{-1} which escalated to 4.9 t ha^{-1} with the addition of RDF$_{100}$. The treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ remained non-significant to each other (4.8 vs. 4.7 t ha^{-1}). Similarly, highest straw yield (7.8 t ha^{-1}) was produced from treatment PM + RDF$_{100}$ followed by FYM + RDF$_{100}$ (7.4 t ha^{-1}), and RDF$_{100}$ (7.1 t ha^{-1}), while minimum straw yield was recorded in control treatment (4.9 t ha^{-1}).

Differential nutrient uptake by wheat under INM

Data regarding nutrient (i.e. nitrogen, phosphorus and potassium) uptake by wheat crop under the integration of organic sources and chemical fertilizers is given in Table 4. Wheat crop exhibited variable response for nutrient uptake by grains and straw when grown with different treatments of organic and inorganic sources. Nutrient uptake improved significantly with the integrated use as compared to sole application of these materials. But the integrated effect of PM was more pronounced than FYM. Minimum grain N uptake (50.3 kg ha^{-1}) was estimated in control treatment that was escalated to maximum (101.9 kg ha^{-1}) in PM + RDF$_{100}$ followed by FYM + RDF$_{100}$ (98.5 kg ha^{-1}). While treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ proved statistically non-significant with each other (94.0 vs. 91.5 kg ha^{-1}). Control plots revealed straw N uptake 10.7 kg ha^{-1} which enhanced to 15.5 kg ha^{-1} with RDF$_{100}$ while reached to maximum (21.9 kg ha^{-1}) in PM + RDF$_{100}$ treatment. Similarly, total N uptake (grain + straw) varied considerably among different treatments and indicated highest (123.8 kg ha^{-1}) in PM + RDF$_{100}$ followed by FYM + RDF$_{100}$ (118.0 kg ha^{-1}) while minimum was recorded in control plots (61.1 kg ha^{-1}). Treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ (111.7 vs. 107.7 kg ha^{-1}), and PM + RDF$_{50}$ and FYM + RDF$_{50}$ (99.4 vs. 97.4 kg ha^{-1}) remained at par to each other.

Table 4. Nutrient uptake (i.e. grain, straw, and total) by wheat in response to integrated plant nutrient management

Treatments	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Control	50.3 f	10.7 f	61.1 f	6.6 e	3.1 e	9.7 g	28.3 d	22.5 c	50.8 g
RDF$_{100}$	92.6 bc	15.5 cd	108.1 c	16.4 bc	7.7 c	24.1 c-e	50.0 ab	33.7 b	83.7 cd
FYM	61.8 e	11.8 ef	73.6 e	9.2 d	4.0 e	13.1 f	33.0 d	23.0 c	56.0 fg
FYM + RDF$_{100}$	98.5 ab	19.5 ab	118.0 ab	20.0 a	9.6 ab	29.5 ab	55.2 ab	38.1 ab	93.3 ab
FYM + RDF$_{75}$	91.5 c	16.1 cd	107.7 c	17.7 bc	7.9 c	25.6 cd	49.5 ab	36.7 ab	86.3 c
FYM + RDF$_{50}$	83.4 d	14.0 de	97.4 d	15.8 c	6.2 d	22.0 e	42.5 c	32.9 b	75.4 e
PM	62.2 e	13.1 d-f	75.3 e	10.6 d	4.2 e	14.8 f	34.1 d	23.5 c	57.6 f
PM + RDF$_{100}$	101.9 a	21.9 a	123.8 a	20.3 a	10.5 a	30.8 a	55.8 a	40.1 a	96.0 a
PM + RDF$_{75}$	94.0 bc	17.6 bc	111.7 bc	18.2 ab	9.1 bc	27.3 bc	49.3 b	39.6 a	88.9 bc
PM + RDF$_{50}$	83.6 d	15.8 cd	99.4 d	17.0 bc	6.1 d	23.1 de	42.8 c	34.9 ab	77.7 de
LSD 0.05	6.06	3.14	7.88	1.03	1.42	3.34	6.34	5.60	6.22

Treatment details are given in Table 2. Treatment means not sharing similar letter(s) in the same column differ significantly from each other (LSD test, $P \leq 0.05$). Values are means of three replications (n = 3)

Combined application of organic and chemical fertilizers significantly enhanced P uptake by wheat crop than the sole addition of chemical fertilizers. The control treatment showed minimum grain P uptake (6.6 kg ha^{-1}) while treatment PM + RDF$_{100}$ accumulated maximum grain P (20.3 kg ha^{-1}). The grain P uptake in FYM + RDF$_{75}$ (17.7 kg ha^{-1}) and PM + RDF$_{75}$ (18.2 kg ha^{-1}) remained statistically identical to the treatment RDF$_{100}$ (16.4 kg ha^{-1}). The highest straw P uptake was estimated in PM + RDF$_{100}$ treatment (10.5 kg ha^{-1}) which remained statistically at par to FYM + RDF$_{100}$ (9.6kg ha^{-1}). The total P uptake by the above-ground plant parts (grain + straw) was recorded minimum in control plots (9.7 kg ha^{-1}) while the treatment PM + RDF$_{100}$ showed maximum value of total P uptake (30.8 kg ha^{-1}) followed by the treatment FYM + RDF$_{100}$ (29.5 kg ha^{-1}) and RDF$_{100}$ (24.1 kg ha^{-1}). Treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ remained at par to each other (27.3 vs. 25.6 kg ha^{-1}). Similarly, treatments PM + RDF$_{50}$ and FYM + RDF$_{50}$ were also assessed statistically non-significant with each other (23.1 vs. 22.0 kg ha^{-1}).

Different treatments comprised of inorganic and organic sources influenced significantly on K uptake by wheat crop. The grain K uptake ranged from 28.3 kg ha^{-1} in the control treatment to 55.8 kg ha^{-1}in PM + RDF$_{100}$ followed by the treatment FYM + RDF$_{100}$ (55.2 kg ha^{-1}) and RDF$_{100}$ (50.0 kg ha^{-1}). Straw K uptake increased with the additional chemical fertilizers, irrespective of organic amendments. Highest straw K uptake (40.1 kg ha^{-1}) was estimated in PM + RDF$_{100}$which remained at par to treatments PM + RDF$_{75}$ (39.6 kg ha^{-1}), FYM + RDF$_{100}$ (38.1 kg ha^{-1}), and FYM + RDF$_{75}$ (36.7 kg ha^{-1}). While minimum straw K uptake was recorded in control treatment (22.5 kg ha^{-1}). Total K uptake (grain + straw) different significantly among various treatments and estimated maximum (96.0 kg ha^{-1}) in PM + RDF$_{100}$ treatment followed by FYM + RDF$_{100}$ (93.3 kg ha^{-1}) while minimum was recorded in control plots (50.8 kg ha^{-1}). Treatments PM + RDF$_{75}$, FYM + RDF$_{75}$ and RDF$_{100}$ indicating values for total K uptake of 88.9, 86.3 and 83.7 remained statistically identical with each other.

Variation in nutrient efficiency relations of wheat under INM

The data regarding nutrient efficiency relations i.e. recovery efficiency, and agronomic efficiency in wheat in response to integrated nutrient management is depicted in Table 5. Recovery efficiencies of NPK were observed higher at lower rates and vice versa. The magnitude of N recovery efficiency varied from 39.2% (RDF$_{100}$) to 63.8% (PM + RDF$_{50}$) followed by FYM + RDF$_{50}$ (60.6%). All other treatment remained non-significant for N recovery efficiency. The minimum P recovery efficiency (16.1%) was calculated with RDF$_{100}$ which escalated to 29.8% with PM + RDF$_{50}$ followed by FYM + RDF$_{50}$ (27.4%). While treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ (26.1 vs. 23.6%), and PM + RDF$_{100}$ and FYM + RDF$_{100}$ (23.5 vs. 22.1%) proved statistically non-significant with each other. The treatment RDF$_{100}$ revealed K recovery efficiency of 54.8% which enhanced to 82.1% with FYM + RDF$_{50}$ while reached to maximum (89.5%) in PM + RDF$_{50}$ treatment.

The agronomic efficiency of nutrients was also recorded higher at lower levels of fertilizers, irrespective of organic sources. The maximum N agronomic efficiency (27.1 kg kg^{-1}) was recorded in treatment PM + RDF$_{50}$ followed by PM + RDF$_{100}$ (24.3 kg kg^{-1}), while RDF$_{100}$ showed minimum value for N agronomic efficiency (18.5 kg kg^{-1}). The treatment PM + RDF$_{50}$ and PM + RDF$_{100}$ exhibited higher P agronomic efficiency by showing values of 36.1 and 32.4 kg kg^{-1} respectively. However, the lowest P agronomic efficiency (24.7 kg kg^{-1}) was observed in plots with RDF$_{100}$ only. The treatment PM + RDF$_{75}$ showed statistically identical results for agronomic efficiency of P with the treatments FYM + RDF$_{100}$, FYM + RDF$_{75}$, and FYM + RDF$_{50}$. The treatment RDF$_{100}$ showed lowest value of K agronomic efficiency (37.0 kg kg^{-1}), while the highest K agronomic efficiency was estimated in PM + RDF$_{50}$ (54.2 kg kg^{-1}) which remained statistically at par to PM + RDF$_{100}$ (48.6 kg kg^{-1}).

Discussion

Plant roots are the main structures for water and nutrient acquisition from soil. Identification and manipulation of favorable plant root traits is a fundamentally important strategy to improve crop productivity on soils with poor fertility status (Meister et al., 2014; Li et al., 2016). Results of current study revealed that root system architecture (RSA) of wheat was influenced significantly under the integrated use of FYM and/or PM along with mineral fertilizers. Increase in root length, root surface area, and number of root tips at lower NPK rates, irrespective of organic sources, is the manifestation of the fact that plants invest more into belowground plant parts in order to explore more soil volume under limited nutrient availability for fulfilling their nutrient requirements (York et al., 2018). Among organic amendments, integrative response of PM was more pronounced in improving root traits as compared to FYM. The improved physical properties in response to INM system might have provided a more desirable soil environment for the better root development. Wheat plants have monocot/fibrous root system having total root length, root volume, root surface area, root diameter and number of roots as major traits (York et al., 2018). Nutrient availability poses profound impact on RSA by manipulating the root length, root diameter, root angle, number of roots and root hairs (Gruber et al., 2013). Wutthida and Karel (2015) studied the effect of nutrient deficiency on RSA of wheat and found that total seminal root, lateral root length and root-shoot ratio increased under N deficiency, while P deficiency revealed higher total root area and average root diameter; nonetheless K deficiency influenced slightly on the RSA of wheat.

Improvement in crop yield is the ultimate target of any nutrient management strategy. Addition of organic amendments on long-term basis along with inorganic fertilizers may enhance soil fertility by increasing organic C, macro and micronutrient contents (Antil et al., 2011). Our results clearly indicated that various treatments contributed effectively to increase wheat yield. Yield response of PM along with chemical fertilizers proved superior to all other treatments. The application of PM + RDF_{100} showed maximum increase in yield and associated traits (Table 3). The benefit of organic sources was quite evident as they ensured a steady nutrient supply, important for better plant growth. Higher availability of plant nutrients released from FYM and/or PM might have contributed in improving yield and related traits. Moreover, contribution of humic substances from these sources along with chemical fertilizers exert positive impact on crop performance by enhancing water and nutrient absorption from soil thereby resulting in yield improvement (Ganaie et al., 2015). Bhandari et al. (2002) found identical results for rice yield with the *Sesbania* green manure plus 50% recommended NPK dose and 100% NPK alone. Wheat yield significantly enhanced with the use of chemical fertilizers along with compost, FYM and *Sesbania* green manure when compared to control (Sabah et al., 2014). Likewise, integration of FYM (15 t ha^{-1}) and chemical fertilizers (250-120-125 kg NPK ha^{-1}) showed the maximum grain yield of 8.47 t ha^{-1} in maize crop (Randhawa et al., 2012). Soomro et al. (2013) reported 25% saving of chemical fertilizers in sugarcane crop under the INM with FYM and/or PM applied at the rate of 20 t ha^{-1}.

Sharma and Sharma (2002) investigated the effect of INM on the sustainability of rice-wheat cropping system and observed higher N uptake of rice-wheat system by 38-45 kg ha^{-1}, P uptake by 7-10 kg ha^{-1}, and K uptake by 25-42 kg ha^{-1} in response to FYM + NPK fertilizer. In current study, nutrient uptake significantly improved with the conjunctive use of inorganic and organic nutrient sources as compared to sole application of these materials. But the integrated effect of PM was superior to FYM (Table 4). Mitra et al. (2010) described that higher nutrient uptake under INM might be due to the release of native nutrients, synthesis of complex intermediate organic molecules during decomposition, their mobilization with different nutrients, and accumulation in various plant tissues. More nutrient uptake under INM can be attributed to additional supply of nutrients through these organic sources. Moreover, the synergistic effect of organic matter addition on the availability of native and applied nutrients could be the reason behind higher nutrient uptake and crop yield. Singh et al. (2006) and Phullan et al. (2017) reported high uptake of macronutrients (N, P and K) in response to addition of FYM and green manure. According to Shah et al. (2009), combined application of organic (poultry manure, filter cake, and FYM) and inorganic sources in the ratio of 25:75 can increase grain yield and N uptake of wheat. Joint application of organic and chemical fertilizers has positive effect on N, P and K contents in sugarcane leaf tissues (Bokhtiar and Sakurai, 2005). Singh et al. (2008) stated that high P availability with the FYM and/or PM along with inorganic P might be due to the addition of P through organic sources in excess of the crop removal. Organic acids produced from decomposition of organic resources facilitate the release of K from the K-bearing minerals, and thus enhance the K uptake by wheat (Ganaie et al., 2015).

In present study, nutrient (NPK) efficiency relations i.e., recovery efficiency and agronomic efficiency were recorded higher at lower fertilizer rates and vice versa. Least recovery efficiency of NPK were calculated with

RDF$_{100}$ while highest were recorded in PM + RDF$_{50}$. Application of pressmud along with RDF$_{50}$ and RDF$_{100}$ produced higher agronomic efficiency of applied nutrients while RDF$_{100}$ of NPK exhibited lowest values (Table 5). Recovery efficiency of any nutrient can be described as the amount of a particular nutrient absorbed by the plant per unit of nutrient applied, while agronomic efficiency refers to the grain yield produced per unit of nutrient applied (Fageria et al., 2010). The enhanced nutrient use efficiency under INM treatments might be attributed to the impact of organic sources on soil quality by favoring the vital soil physical, chemical, and biological processes that must occur in order to support plant growth (Bronick and Lal, 2005). Yaduvanshi (2003) reported that conjunctive use of mineral fertilizers and FYM increase nutrient efficiency in wheat (2.2%) and rice (30.6%). Similarly, Shah et al. (2009) found that organic and mineral nutrient sources in 25:75 are the best combination to achieve high nutrient use efficiency and sustainable yield of wheat crop. Abbas et al. (2016) reported that nutrient efficiency can be enhanced using suitable combination of organic and mineral sources and tightening the ratio of nutrients signifying that a rational merger of elements is crucial to improve their efficiency.

Table 5. Recovery and agronomic efficiencies of nitrogen, phosphorus, and potassium in wheat crop under integrated plant nutrient management

Treatments	Recovery efficiency (%)			Agronomic efficiency (%)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Control	-	-	-	-	-	-
RDF$_{100}$	39.2 d	16.1 c	54.8 e	18.5 c	24.7 c	37.0 c
FYM	-	-	-	-	-	-
FYM + RDF$_{100}$	47.4 cd	22.1 b	70.8 bc	22.2 bc	29.6 bc	44.4 bc
FYM + RDF$_{75}$	51.8 bc	23.6 b	78.7 ab	22.1 bc	29.5 bc	44.2 bc
FYM + RDF$_{50}$	60.6 ab	27.4 ab	82.1 ab	21.8 bc	29.1 bc	43.6 bc
PM	-	-	-	-	-	-
PM + RDF$_{100}$	52.3 bc	23.5 b	75.2 b	24.3 ab	32.4 ab	48.6 b
PM + RDF$_{75}$	56.2 a-c	26.1 ab	84.7 ab	23.8 ab	31.8 ab	47.7 ab
PM + RDF$_{50}$	63.8 a	29.8 a	89.5 a	27.1 a	36.1 a	54.2 a
LSD 0.05	10.49	5.47	17.52	4.45	5.94	8.91

Treatment details are given in Table 2. Treatment means not sharing similar letter(s) in the same column differ significantly from each other (LSD test, $P \leq 0.05$). Values are means of three replications (n = 3)

Conclusion

The results of current study suggested that integration of organic and mineral nutritional sources could be a sustainable strategy to maximize wheat productivity and nutrient efficiency on low-fertile alkaline calcareous soils. Although both organic sources (PM and FYM) improved root system, grain yield and nutrient uptake in wheat, but the integrative response of PM was most evident than FYM. Integrated use of PM along with RDF$_{100}$ proved superior to all other treatments, indicating the highest grain yield and NPK uptake. Moreover, treatments PM + RDF$_{75}$ and FYM + RDF$_{75}$ showed statistically identical yield with RDF$_{100}$, suggesting that 25% mineral fertilizers can be saved through this integration approach. However, further evaluation of this approach on different soil types is needed to devise concrete recommendations for adoption on a wider scale.

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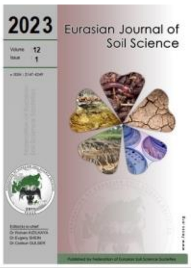

The effects of feeding with organic waste by terrestrial isopod *Philoscia Muscorum* on enzyme activities in an incubated soil

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Abstract

Soil fauna are important biological factors that affect litter decomposition and play an important role in the release of nutrients and improve soil enzyme activities. This study focused on the effects of isopods on enzymatic activities of soil. Lab experiments were conducted to assess the influence of terrestrial isopod Philoscia Muscorum on enzyme activities during the incubation. In Lab experimental food sources from wheat straw were prepared. Dehydrogenase, urease, alkaline phosphatase and arylsulphatase activity in soil treated with different number of isopods with wheat straw were determined in 28 days incubation. Results showed that the presence of isopods significantly increased ($P<0.05$) enzymatic activities of soil except arylsulphatase compared with the control treatment. The findings demonstrate that the isopods could accelerate litter decomposition and improve soil dehydrogenase, urease and alkaline phosphatase activities in soil. This work provides evidence demonstrating that soil fauna can improve soil enzyme activity by promoting wheat straw decomposition.

Keywords: Isopod, dehydrogenase, urease, alkaline phosphatase, arylsulphatase, soil.

Introduction

Litter fragmentation is the first step in the recycling of organic matter. Soil macrofauna affect litter decomposition and available nutrient contents in soil by influencing the microorganisms and their activities (Morgan and Mitchell, 1987). Isopods transport organic material deeper into the substrate. In addition, soil nutrients such as N, P and S are affected by macrofaunal activity through changes in substrate-decomposition rates and increased substrate surface area (Seastedt and Crossley Jr., 1980; Visser, 1985; Morgan and Mitchell 1987; Anderson, 1988a,b). It comprises primary attack of the protecting cuticle and epidermis and further comminution of leaves, thereby increasing the surface area of the litter particles and mixing litter particles intimately with microorganisms. These processes strongly favour microbial attack and, hence, mineralization of the organic substances from plant cells. When microbial processes taper off, renewed fragmentation or grazing by fungivores will revive microbial activity (Eijsackers, 1991). As a consequence, terrestrial isopods indirectly affect the activity and community composition of the soil microflora and their activities (Teuben and Roelofsma, 1990). The isopod *Philoscia muscorum* is a common and abundant member of the saprophagous soil macrofauna in Kazakhstan (Bragina and Khisametdinova, 2014).

The ecological function of isopods has been extensively studied, but little research has been conducted on the effects of isopods on soil enzymatic activities. Therefore, evaluating the relationship among isopods, their feds

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and soil is necessary. A comparison of enzyme activities in a soil with and without terrestrial isopods should further illuminate the effect of terrestrial isopods on enzymatic activity in soil ecosystem. The objective of the present study was to examine the effects of terrestrial isopod *Philoscia Muscorum* on enzymatic activity in loamy soil. These results will help understanding the effect of isopod Philoscia Muscorum on enzymatic activity in soil.

Material and Methods

Soil, organic waste and isopod *Philoscia Muscorum*

The surface soil (0-20 cm) used in this experiment and contained 14.45% clay, 42.65% silt, 42.9% sand. Soil texture can accordingly be classified as loam (L). The pH in water was 7.26, electrical conductivity in water was 0.11 dSm^{-1}, $CaCO_3$ content was 5.76%, the oxidizable organic matter content was 1.25%, the total N was 0.018%, $NaHCO_3$ extractable P was 5.86 mg kg^{-1}, the soil C:N ratio was 40.3. The soil was bulked, all stones, visible roots and fauna removed, sieved to less than 2 mm and stored at 5^0C until used. Wheat Straw as an organic waste was obtained from the field after wheat harvesting. The wheat straw was composed of approximately 92% by weight of oxidable organic matter. The organic fraction comprised 53% C and 0.42% N while the inorganic fraction contains 0.25% P_2O_5 and 4.77% K_2O by weight. The wheat straw in this experiment was digested and air dried and sieved to less than 1 mm and stored in polyethylene bags at 5^0C until used. Also *Philoscia muscorum* (Isopod; Philosciidae) which was used in the experiment, has been collected from the field.

Experimental procedure

On top of 50 gr air-dried soil which was contained within 150 ml glass containers, 10% (5 g) wheat straw has been added. Afterwards, the moisture content of the soil has been moistened with distilled water enough to be at field capacity level. Subsequently, on top of the soils *Philoscia muscorum* has been added in increasing numbers (0, 5, 10, 15 and 20 piece/50gr). The glass containers containing the soil, organic material and *Philoscia muscorum* has been left to incubation (25±2^oC) in the laboratory. The experiment established as 3 replications, and formed with 60 glass containers. During incubation, by weighing every day, the diminished water from the soil re-added to the medium, and properties of the soil samples which were taken in 7th, 14th, 21st and 28th days of the incubation has been determined in 3 parallels.

Measurement of soil enzymatic activities

Dehydrogenase activity was determined according to Pepper et al. (1995). Six grams of soil, 30 mg glucose, 1 ml of 3% 2,3,5-triphenyltetrazoliumchlorid (TTC) solution and 2.5 ml pure water were added. The samples were incubated for 24h at 37^oC. The formation of 1, 3, 5 triphenylformazan (TPF) was determined spectrophotometrically at 485 nm and results were expressed as μg TPF g^{-1} dry sample $24h^{-1}$.

Urease activity was measured by the method of Hoffmann and Teicher (1961). 0.25 ml toluene, 0.75 ml citrate buffer (pH, 6.7) and 1 ml of 10% urea substrate solution were added to the 1 g sample and the samples were incubated for 1h at 37^0C. The formation of ammonium was determined spectrophotometrically at 578 nm and results were expressed as μg N g^{-1} dry sample.

Alkaline phosphatase activity was determined according to Tabatabai and Bremner (1969). 0,25 ml toluene, 4 ml phosphate buffer (pH,8.0) and 1 ml of 0,115 M *p*-nitrophenyl phosphate (disodium salt hexahydrate) solution were added to the 1 g sample and the samples were incubated for 1h at 37^0C. The formation of *p*-nitrophenol was determined spectrophotometrically at 410 nm and results were expressed as μg *p*-nitrophenol g^{-1} dry sample.

Arylsulphatase activity was measured according to Tabatabai and Bremner (1970). 0.25 ml toluene, 4 ml acetate buffer (pH,5.5) and 1 ml of 0.115 M *p*-nitrophenyl sulphate (potassium salt) solution were added to the 1 g sample and the samples were incubated for 1h at 37^0C. The formation of *p*-nitrophenol was determined spectrophotometrically 410 nm and results were expressed as μg *p*-nitrophenol g^{-1} dry sample.

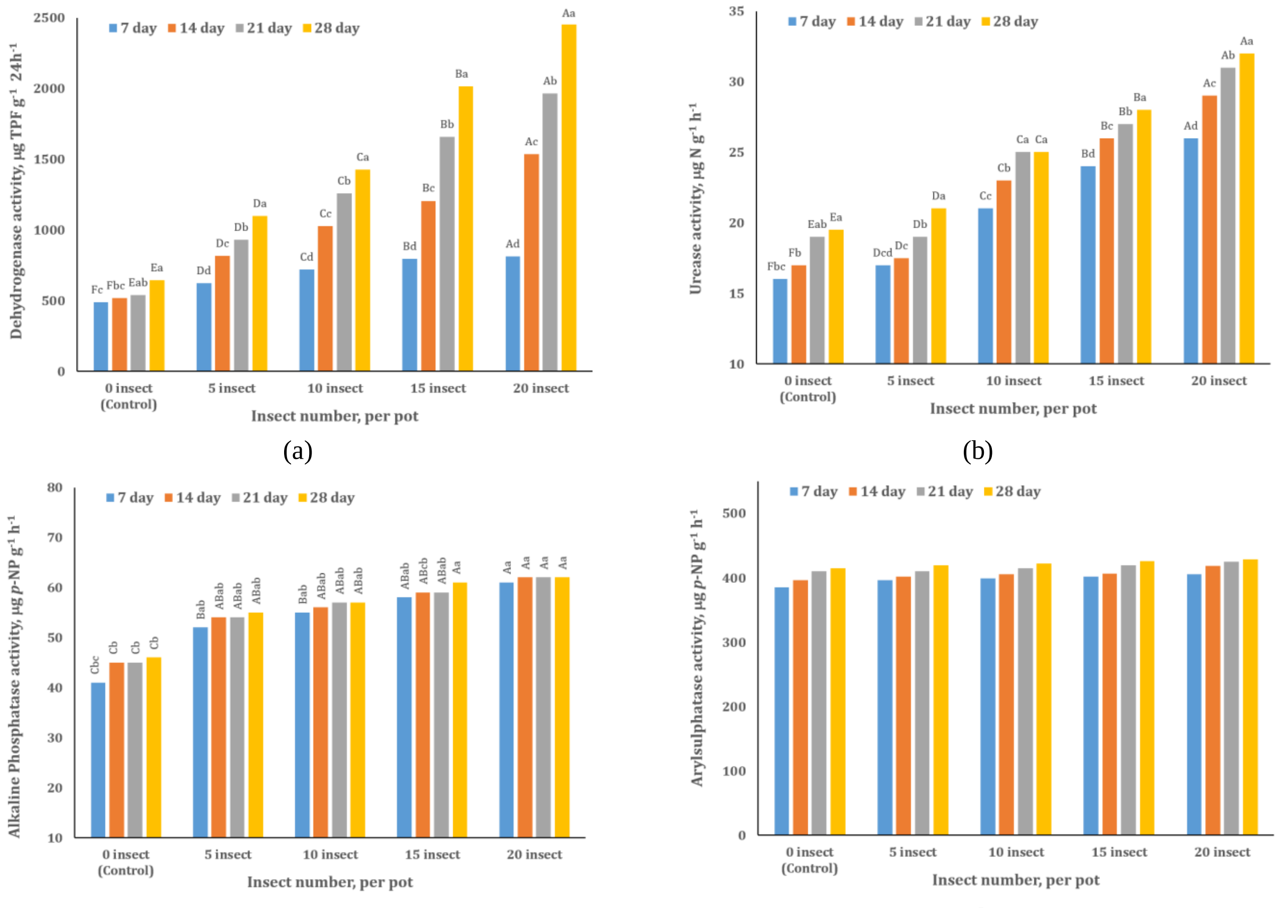
All determination of enzymatic activities were performed in triplicate, and all values reported are averages of the three determinations expressed on an oven-dried soil basis (105 ^{0}C).

Statistical Analysis

In order to perform the ANOVA test for the results obtained from the experiments and to demonstrate the statistical differences, the LSD test has been performed with SPSS 11.0 statistical software package.

Results and Discussion

The changes in the enzyme activities of the soils during the 28-day incubation period with the addition of an increasing number of terrestrial isopod *Philoscia Muscorum* to the soils are shown in Figure 1. According to the results obtained, it was determined that the isopods added to the soils affect the activities of different enzymes in the soils differently. Isopods exert direct and indirect effects on the promotion of litter decomposition (Jia et al., 2015). Our study showed that isopod treatment can significantly ($P < 0.05$) promote enzymatic activities except arylsuphatase compared with control treatment. Two main reasons account for this phenomenon. First, isopods can directly feed and break down wheat straw to improve its decomposition. Second, they can indirectly change the quantity, structure, and activity of soil microbial communities (Jia et al., 2015). Macro-detritivores feed on large amounts of litter and expel the resulting organic material in the form of feces, which could reach a critical level of energy and nutrient input for soil microorganisms (Hunter, 2001; Clark et al., 2010; Yang et al., 2020). According to this results, it can be said that isopods have a greater effect on soil enzymatic activities. These effects were most profound during the incubation periods of the present experiments, when synthesis of enzymes by microorganisms are expected to be dominant.



(a) (b)

(c) (d)

Figure 1. The impact of isopod *Philoscia muscorum* added in increasing numbers to the soil mixed with 10% wheat straw, on the soil enzyme activities (a) Dehydrogenase activity (b) Urease activity (c) Alkaline phosphatase activity (d) Arylsulphatase activity

During the incubation period, it was determined that the change in soil enzyme activities after the application of terrestrial isopod *Philoscia Muscorum* to the soil in increasing numbers with wheat straw was most evident in dehydrogenase activity (Figure 1). In the control application (0 insect), it was determined that dehydrogenase activity increased when only wheat straw was given to the soil ($P<0.05$). In many studies (Kızılkaya, 2008), it has been determined that the dehydrogenase activity of the soils increases when organic matter is added to the soil. However, it was determined that insect added to the soil in increasing numbers increased the dehydrogenase activity, and this increase was more in the later stages of incubation ($P<0.05$). The highest dehydrogenase activity was determined in soil treated with 20 insect and on the 28th day of incubation (Figure 1a). As presence of dehydrogenases, which are intracellular to the microbial biomass, is common throughout microbial species and they are rapidly degraded following the cell death, the measurement of microbial dehydrogenase activity in soils and sediments has been used extensively (Bolton Jr. et al., 1985; Rossel and Tarradellas, 1991; Obbard, 2001). Therefore, usage of dehydrogenase activity as an index of microbial activity has been suggested (Benefield et al., 1977; Masciandaro et al., 2000; Zhang et al., 2006). The increase in the dehydrogenase activity of isopod added to the soil in increasing numbers at the end of this experiment reveals that it is an important indicator that the microbial activity of the soils has increased.

It has been determined that terrestrial isopod *Philoscia Muscorum* added to soils in increasing numbers increase urease activity as well as dehydrogenase activity. It was determined that there was an increase in the urease activity of the soils by adding only wheat straw to the soil in the control soil without isopod (Figure 1b). Urease is involved in the hydrolysis of urea to carbon dioxide and ammonia, which can be assimilated by microbes and plants. It acts on carbon-nitrogen (C-N) bonds other than the peptide linkage (Bremner and Mulvaney, 1978; Karaca et al., 2002; Kızılkaya and Bayraklı, 2015). In the experiment, the highest urease activity was determined in the application with 20 insect and on the 28th day of incubation. The reason for the increase in urease activity with the addition of isopod is thought to be due to the synthesis of the urease enzyme by this microflora by the increased microbiological activity.

The change in the alkaline phosphatase activity of the soils during the 28-day incubation period of the soils with increasing numbers of isopods added with wheat straw is given in Figure 1c. According to the results, it was determined that the addition of terrestrial isopod *Philoscia Muscorum* increased the phosphatase activity of the soils compared to the control. Although there was no significant relationship between incubation period, the highest phosphatase activity was detected on the 28th day of incubation and 20 insect additions. Phosphatase is an enzyme of great agronomic value because it hydroles compounds of organic phosphorus and transforms them into different forms of inorganic phosphorus, which are assimilable by plants (Amador et al., 1997). Variations in phosphatase activity apart from indicating changes in the quantity and quality of a soil's phosphorated substrates, are also a good indicator of its biological state (Pascual et al., 1998, 2002). In this experiment, it was determined that the addition of insects to the soil was more effective than the incubation period on the change in alkaline phosphatase activity determined in different incubation periods. In addition, an increase in soil phosphatase activity was detected in the last periods of incubation in the control application without insect. With the studies carried out by other researchers (Akça and Namlı, 2015), it has been determined that organic materials added to the soil increase the phosphatase activity of the soils.

The effect of isopods added to the soil in increasing numbers together with wheat straw on the arylsulphate activity of the soils is given in Figure 1d. According to the results obtained, the effects of isopod addition on the arylsulphate activity of the soils were not found to be statistically significant. Arylsulphatase is the enzyme involved in the hydrolsis of arylsulphate esters by fission of the oxygen-sulphur (O-S) bond. This enzyme is believed to be involved in the mineralisation of ester sulphate in soils (Tabatabai, 1994). Also, it may be an indirect indicator of fungi as only fungi (not bacteria) contain ester sulphate, the substrate of arylsulphatase (Bandick and Dick, 1999). According to the results obtained, the effects of isopod addition on the arylsulphate activity of the soils were not found to be statistically significant.

Conclusion

Our results indicated that terrestrial isopod *Philoscia Muscorum* can significantly promote wheat straw decomposition and isopods could significantly improve the soil enzymatic activities of soil during the incubation. The promotion of soil enzymatic activities by the isopods was significantly affected by insect numbers, incubation time, and their interactions. This work highlights the interconnections between isopods and soil enzyme activities and the importance of further research on the ecological functions of soil fauna.

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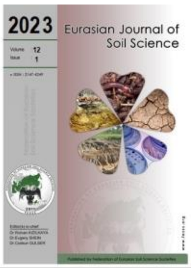

Micromorphological soil assessment in abandoned quarry dumps of the Central Caucasus, Russia

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Abstract

This study compared the micromorphological and agrochemical metrics in soils from the quarry dumps and zonal soils, the Central Caucasus. Soil micromorphological investigations are important tool for evaluation of soil dynamics after anthropogenic impacts on terrestrial ecosystems. The results showed that the carbon content in the primary soil of the sand and gravel quarries was lower than that in the reference soil. The differences detected were statistically significant for both the Urvan plot soils (t = 11.95; p = 0.000) and the Progress plot soils (t = 18.73; p = 0.000). In contrast, in the quarry with clay bottom substrate (Gerpegezh), no significant difference was found between the reference and postmine soils. The reference soil around the sand and gravel quarries was slightly more acidic than the primary soil. In the clay quarry, the primary soil was more acidic with a strong acidic value, while the reference soil was neutral. The difference of nutrients (P, K, NH_4^+, NO_3^-) between the primary and reference soils were negligible. The only exception was the NO_3^- content in the reference soil of Progress settlement, where it was significantly higher (t = 4.19; p = 0.002) than in the original soil of the site. No difference was observed for the mineral component of the primary soil. Investigation of key zonal soils of the region. Zonal Caucasus soils: Phaeozem Gleiyc, Phaeozem and Umbric Retisol are different in terms of micro texture. Thus, Phaeozem Gleiyc characterizes by microstructure composed by primary angular mineral forms. Phaeozem and Retisol demonstrated formation of biogenic structure with alteration of mineral particles. Data obtained show that rapid self revegetation of the quarries results in initialization of primary soil formation and transformation of the soil microstructure and organization on the micro level.

Keywords: Central Caucasus, primary soil, soil micromorphological feature, quarry dumps, zonal soil.

Introduction

Land degradation is a major global ecological problems (Gregory et al., 2015; Bagarello et al., 2018). The key factor of terrestrial ecosystems changes is various mineral deposits exploitation with use of mining technologies. Minerals are extracted by mining, open-pit, and combined methods. Open-pit (quarry) extraction is the dominant method for mining due to its low-cost (Abakumov and Gagarina, 2006). However, this method can have a great damage on the landforms (GRLD, 1976). For example, open-pit mining in forest areas is associated with deforestation, draining, and changing of hydrological regime. Negative changes occur not only at the extraction sites but also in the adjacent areas. Previous studies showed that the areas affected by open-pit mining are much larger than the mine itself (Bekarevich and Masyuk, 1969; Melnikov, 1977).

Numerous degraded soil areas have been reported in the Central Caucasus regions, including 3400 ha and 1007 ha of degraded soil in Stavropol Krai and Kabardino-Balkarian Republic, respectively (SRLS, 2019). These regions are dominated by the extraction of common minerals such as boulder-sand-gravel mixes,

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construction sand, and building stone. There are 171 quarries in Stavropol Krai and 53 quarries in Kabardino-Balkaria. These quarries include sand-and-gravel, sandpits, stone pits, brick-and-tile pits, and deposits of keramzite clays, brick loam quarries, volcanic ash and pumice, deposits of tuff, limestone, granite, argillite clay, technical waste, gypsum, sand, and bentonite. The minerals extracted in the Central Caucasus are mostly used for construction (SRLS, 2019; Khamarova, 2019).

Agrochemical and biological soil properties have been used to study artificially-disturbed lands (Gavrilenko et al., 2011; Murugan et al., 2014; Gorobtsova et al., 2016a; Kazeev et al., 2020). However, micromorphological properties were not used for investigation of soils of this region. Despite the fact that micromorphological methods are not often used, they are an important tool for studying soil changes under anthropogenic influences (Stoops and Eswaran, 1986; Lebedeva et al., 2016; Zgangurov et al., 2018). Thus, works on the effects of toxic metals on soil fauna activities and hence on the ecological functions of soils (Acosta et al., 2011) and the effects of the combined addition of organic and industrial waste on stimulating soil formation in degraded landscapes left by extensive mining activities (Arocena et al., 2012) show that soils are best evaluated by knowing the distribution of metals and organics in solid soil phases using micromorphological methods. Micromorphological methods allow the assessment of general physicochemical and biological indicators of soil quality by determining the mineral composition, porosity, quality and quantity of organic matter (Lebedeva-Verba and Gerasimova, 2009; Gerasimova and Lebedeva-Verba, 2010). The conventional soil micromorphology approaches can provide the information about the soil evolution at the micro-level (Stoops and Eswaran 1986, Gerasimova et al., 1992). Micromorphological studies can help identify various physical properties of soils, the nature of minerals, and their relationships with organic matter (van Mourik, 1999; Srivastava et al., 2009; Francis and Poch, 2019; Ageeb et al., 2019). Micromorphological methods have also been used to study degraded landscapes formed after mining (Arocena et al., 2010; Doroshkevich et al., 2020) and their reclamation (Abakumov et al., 2005; Arocena et al., 2012). In the Central Caucasus there are large areas of degraded land, formed as a result of open-cast mining. But there are no works devoted to the assessment of these lands with the use of micromorphological and agrochemical methods of research. On this basis, the aim of the present study was a comparative analysis of micromorphological and agrochemical indicators of soils formed on the waste dumps of open-pit complexes, compared with undisturbed benchmark soils of adjacent landscapes on the example of the Central Caucasus (Stavropol Territory and Kabardino-Balkar Republic).

Material and Methods

Study area

The study area was located in the Central Caucasus, Stavropol Krai and the Kabardino-Balkarian Republic. The surveyed sites are categorized (Sokolov and Tembotov, 1989) as steppes (200-400 m asl), the broad-leaved forest belt (600-1700 m asl) of the Elbrus zonality, and the meadow steppes belt (400-800 m asl) of the Terek zonality for the Central Caucasus. This area has a moderately humid climate with warm summers and cold winters. The average annual precipitation reaches 750-800 mm, and the average annual air temperature varies from 8.5 to 10.0 °C. The steppe zone is characterized by an arid climate with the precipitation is 400-500 mm/year. The climate is more humid in the meadow steppes belt with the average annual rainfall ranges from 600 to 700 mm/year, while the precipitation in the broad-leaved forest area is about 900 mm/year (Sokolov and Tembotov, 1989).

We studied abandoned quarries at three sites in the Central Caucasus at their revegetation stage. Two sites were in Kabardino-Balkaria and one site was in Stavropol Krai (Figure 1). A total of 5 quarries and 3 soil sections each site with different soil types were investigated. The soils were analyzed and classified under the World Reference Base for Soil Resources (WRB, 2015).

The parent materials of the study areas are represented by Quaternary deposits: yellow-brown and brown-brown carbonate loams and clays, as well as loess-like loams (Molchanov, 1984; Gorobtsova et al., 2021).

The first site is located in the steppe zone of the Terek zonality in the Central Caucasus next to Urvan settlement, Urvan District, Kabardino-Balkarian Republic where two sand-and-gravel quarries (Quarry No. 1 and No. 2) were studied there. The quarries are located on both banks of the Urvan River. The soils at the sample points are Phaeozem Gleic. The second site is in the meadow steppes of the Central Caucasus close to Progress settlement, Kirovsky District, Stavropol Krai. The area narrowly extends into the territory of Kabardino-Balkaria where two sand-and-gravel quarries (quarry No. 3 and No. 4) were investigated. The soils at the sample points are Phaeozems. The third site is located in the wide-leaved belt zone in the Central Caucasus next to Gerpegezh settlement, Cherek District, Kabardino-Balkarian Republic where one clay quarry (quarry No. 5) was studied. The soil at the sample point is Umbric Retisol.

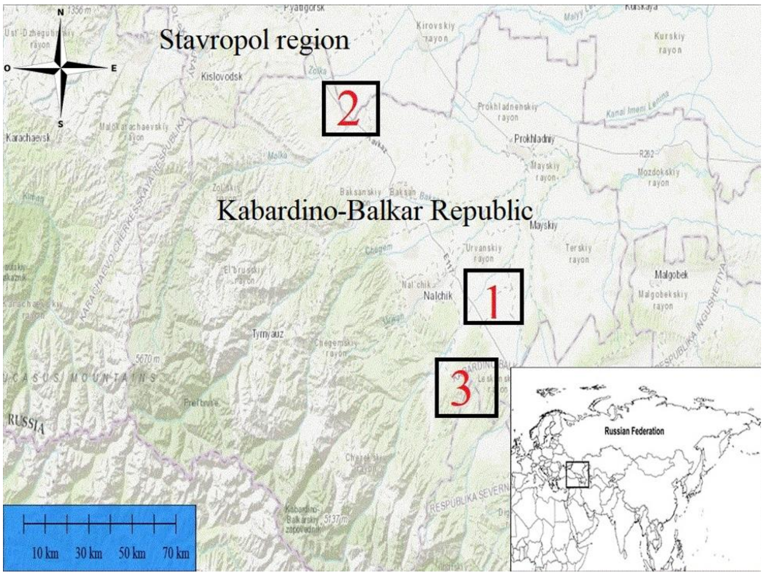

Figure 1. Studied sites. Quarries 1: sand and gravel pit (Urvan); Quarries 2: sand and gravel pit (Progress); Quarries 3: clay pit (Gerpegezh).

Two types of samples were collected in the field. Totally 42 samples were collected. The first type was a 150 g soil sample for lab analysis. The second type was a 2×2×1 cm (H×L×T) micro monoliths. Two to four samples were taken at each site for micromorphology (micromonnolith) and agrochemical analysis (150 g) (Arinushkina, 2013). The samples were taken from the surface layer because they are the most sensitive to various changes. The sample point properties for each site are listed in Table 1.

Soil Chemical Analysis

The carbon content in shallow soils was measured by direct combustion with an elemental analyzer (Euro-EA3028-HT). The pH values of soil solution were measured by the using a pH-meter-millivoltmeter pH-150MA ("Antech", Belarus). Soil solution was prepared in the ratio of 1:2.5 with water. The content of available forms of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^- -N) were determined using potassium chloride solution (ISO/TS 14256-1, 2003). The content of mobile potassium and phosphorus was determined by the Kirsanov method (Sparks et al., 1996; GOST, 2011). The method is based on the extraction of mobile compounds of phosphorus and potassium from the soil with a solution of 0.2 M hydrochoric acid (HCl). The results were statistically processed in Statistica 10.0 and Excel software. The statistical processing included using the *t*-test to measure the statistical significance of the difference between the variables. Spearman's correlation coefficients were also estimated. The significance level for this study was $p \leq 0.05$.

Micromorphological Studies

The objects of the study were micro monoliths of primary soil samples from the quarries and of the reference soils (usually sampled in pairs). The micromorphological studies followed the guidelines by Parfenova and Yarilova (1977), and the manual by Gagarina (2004). The sections were examined and photographed with a Leica MC 170 HD polarization microscope. The microphoto images (Figure 2-10) show transmitted light photos (parallel nicoles) on the left, and photos with the analyzer actuated (crossed nicoles) on the right.

Results

Soil agrochemical characterization

Table 2 lists the chemical properties of the soil surface layer. The studied soils were neutral and slightly alkaline, except for the Leptosol in the Gerpegezh settlement quarry due to the chemical composition of the mineral waste. The primary soils of the site showed a strongly acidic reaction, while the reference soil is neutral, and the differences are statistically significant (t = 7.11; $p < 0.02$).

The organic carbon content in the studied primary soils was low. Despite this, the primary soils formed in the sand-and-gravel quarries contained less carbon than that in the reference soils. The differences were statistically significant both for the Urvan settlement soils (t = 11.95; $p = 0.000$) and the Progress settlement soils (t = 18.73; $p = 0.000$). In contrast, the organic carbon content in the primary soils sampled in the clay quarry near Gerpegezh settlement was higher than in the reference soil (t = 3.51; $p = 0.02$). This can be explained that the reference samples with Umbric Retisol at this site was taken in a beech-horn-dead forest.

Table 1. Research object properties.

Site No.	Horizon	Depth(cm)	Soil	Coordinates
Fig. 2. Overgrowing bottom of quarry No.1, near Urvan settlement, Urvan, right bank of the Urvan River				
N1-1	A	0-3	Leptosol/Sand	N 43.505832° E 43.775770°
N1-2	A	0-2	Leptosol/Sand	N 43.505926° E 43.775748°
N1-3	A	0-3	Leptosol/Sand	N 43.505818° E 43.775559°
N1-4	A	0-3	Leptosol/Sand	N 43.505832° E 43.775770°
Fig. 3. Overgrowing bottom of quarry No.2, near Urvan settlement, left bank of the Urvan River				
N3-1	A	0-2	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
N3-2	A	0-4	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
N3-3	A	0-3	Leptosol Umbric Calcaric Gleyic/Sand	N 43.511371° E 43.772516°
Fig. 4. Reference soil, near Urvan settlement, above the wall of quarry No.1 MATURE				
N2-1	A	0-12	Leptosol Umbric Calcaric Gleyic/Sand	N 43.504599° E 43.775571°
N2-1	B	12-20	Leptosol Umbric Calcaric Gleyic/Sand	
N2-1	C	20-28	Leptosol Umbric Calcaric Gleyic/Sand	
Fig. 5. Bottom of quarry No. 3, grassy vegetation area, near Progress settlement				
N5-1	A	0-4	Leptosol Umbric Petrocalcic Gleyic/Sand	N 43.822996° E 43.331634°
N5-2	A	0-5	Leptosol Umbric Petrocalcic Gleyic	N 43.823000° E 43.331664°
N5-3	A	0-4	Leptosol Umbric Petrocalcic Gleyic	N 43.822671° E 43.332096°
Fig. 6. Bottom of quarry No. 4, a plot given for pasture, vicinity of the settlement. Progress				
N6-1	AU	0-6	Leptosol Umbric Calcaric /Sand	N 43.831616° E 43.347615°
N6-2	AU	6-12	Leptosol Umbric Calcaric /Sand	N 43.831616° E 43.347615°
N6-3	AU	12-30	Leptosol Umbric Calcaric /Sand	N 43.831788° E 43.347126°
Fig. 7. Bottom of quarry No. 4, area with new hillside dumps, near Progress settlement				
N7-1	A	0-10	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829922° E 43.350023°
N7-2	A	0-12	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829818° E 43.349988°
N7-3	A	0-10	Leptosol Umbric Calcaric Nudilithic/Sand	N 43.829650° E 43.350224°
Fig. 8. Reference soil, near Progress settlement, above the wall of quarry No. 3 MATURE				
N4-1	AU	0-25	Phaeozem / Loam	N 43.823767° E 43.332439°
N4-1	AUe	25-50	Phaeozem / Loam	
N4-1	BI	50-70	Phaeozem / Loam	
N4-1	C	70-90	Phaeozem / Loam	
Fig. 9. Overgrown bottom of quarry No. 5, near Gerpegezh settlement				
N9-1	A	0-3	Leptosol/Loam	N 43.371111° E 43.623391°
N9-1	C	3-20	Leptosol/Loam	
N9-2	A	0-2	Leptosol/Loam	N 43.370927° E 43.623366°
N9-2	C	2-25	Leptosol/Loam	
N9-3	A	0-23	Leptosol/Loam	N 43.371198° E 43.623161°
N9-3	B	23-35	Leptosol/Loam	
N9-3	C	35-50	Leptosol/Loam	
Fig. 10. Reference soil, near Gerpegezh settlement, above the wall of quarry No. 5 MATURE				
N8-1	A	0-12	Retisol Folic Inclinic/Loam	N 43.371051° E 43.622333°
N8-1	B	12-20	Retisol Folic Inclinic/Loam	
N8-1	C	20-35	Retisol Folic Inclinic/Loam	
N8-2	A	0-15	Retisol Folic Inclinic/Loam	N 43.371000° E 43.622275°
N8-2	B	15-25	Retisol Folic Inclinic/Loam	
N8-2	C	25-34	Retisol Folic Inclinic/Loam	
N8-3	O	0-2	Retisol Folic Inclinic/Loam	N 43.370858° E 43.622207°
N8-3	A	2-18	Retisol Folic Inclinic/Loam	
N8-3	B	18-27	Retisol Folic Inclinic/Loam	
N8-3	C	27-35	Retisol Folic Inclinic/Loam	

For all the other studied chemical properties, there was no difference between the primary and reference soils. The only exception was the NO_3 content. It was significantly higher ($t = 4.19$; $p = 0.002$) in the reference Phaeozem soil of Progress settlement than in the primary soil of the site.

The Spearman correlation coefficient (Table 3) indicated a strong negative relationship between the content of ammonium and nitrate nitrogen compositions. The exchangeable phosphorus content positively correlated with the content of ammonium nitrogen compositions and negatively correlates with the nitrates content. No strong correlations were found for the other chemical composition properties.

Table 2. Soil chemical composition.

Point	Soil skeleton (%)	C_{org} (%)	pH of salt extract	$P\text{-}P_2O_5$ (mg/kg)	$K\text{-}K_2O$ (mg/kg)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)
Primary soils, Urvan settlement							
N1-1	15	0.29	7.7	34.4	259.7	44.96	0.10
N1-2	20	0.56	7.4	69.9	360.8	79.93	0.10
N1-3	17	0.34	7.4	43.0	274.2	54.46	0.10
N1-4	28	0.45	8.0	35.2	303.0	38.50	0.10
M ± σ	20±5.72	0.41±0.12	7.63±0.29	45.63±16.64	299.43±44.70	54.46±18.20	0.10±0.00
N3-1	18	0.41	8.0	16.1	173.2	23.76	0.10
N3-2	17	0.36	7.9	30.9	303.0	36.55	0.10
N3-3	18	0.41	7.7	44.1	346.3	38.14	0.10
M ± σ	17.67±0.58	0.39±0.03	7.87±0.15	30.37±14.01	274.17±90.08	32.82±7.88	0.10±0.00
Reference soil, Urvan settlement							
N2-1	12	1.89	7.6	17.7	173.2	15.84	5.20
N2-2	11	2.71	7.5	40.1	389.6	37.34	0.10
N2-3	13	2.69	7.6	32.3	288.6	25.59	0.10
M ± σ	12±1	2.43±0.47	7.57±0.06	30.03±11.37	283.8±108.3	26.26±10.77	1.8±2.95
Primary soil, Progress settlement							
N5-1	32	0.78	7.5	12.4	331.9	4.75	8.47
N5-2	21	0.63	7.5	15.1	404.0	6.46	7.80
N5-3	27	0.65	7.6	14.0	317.5	5.30	13.49
M ± σ	26.67±50.51	0.69±0.08	7.53±0.06	13.83±1.36	351.13±46.35	5.50±0.87	9.92±3.11
N6-1	15	0.78	7.5	41.9	692.6	29.91	0.10
N6-2	16	0.79	7.5	42.8	678.2	32.04	0.10
N6-3	15	0.74	7.5	43.0	793.7	30.16	1.15
M ± σ	15.33±0.58	0.77±0.03	7.5±0.00	42.57±0.59	721.50±62.94	30.70±1.16	0.45±0.61
N7-1	25	0.87	7.3	25.5	606.1	12.67	5.20
N7-2	24	0.81	7.4	80.9	894.7	29.18	0.56
N7-3	27	0.82	7.2	21.2	606.1	18.40	0.33
M ± σ	25.33±1.53	0.83±0.03	7.3±0.1	42.53±33.30	702.3±166.62	20.08±8.38	2.03±2.75
Reference soil, Progress settlement							
N4-1	25	2.56	7.1	14.0	404.0	13.83	15.60
N4-2	23	2.21	6.9	14.5	389.6	12.37	33.32
M ± σ	24±1.41	2.39±0.25	7±0.14	14.25±0.35	396.8±10.18	13.1±1.03	24.46±12.53
Primary soil, Gerpegezh settlement							
N8-1	15	1.12	4.9	19.1	375.2	15.90	0.10
N8-2	14	0.75	5.2	19.6	490.6	22.05	0.10
N8-3	21	0.63	5.7	25.3	505.1	58.00	0.10
M ± σ	16.67±3.79	0.83±0.26	5.27±0.40	21.33±3.44	456.97±71.18	31.98±22.74	0.10±0.00
Reference soil, Gerpegezh settlement							
N9-1	23	0.34	7.2	10.8	966.8	10.84	0.11
N9-2	27	0.31	7.3	56.5	1125.5	51.54	0.37
N9-3	30	0.09	6.9	13.7	562.8	27.90	0.10
M ± σ	26.67±3.51	0.25±0.14	7.13±0.21	27±25.59	885.03±290.1	30.09±20.44	0.19±0.15

Table 3. Spearman rank-order correlation coefficients.

Variable	Spearman Rank Order Correlations - Marked correlations are significant at $p < 0.05$						
	Soil skeleton	C_{org}	pH of salt extract	$P\text{-}P_2O_5$, mg/kg	$K\text{-}K_2O$, mg/kg	NH_4^+, mg/kg	NO_3^-, mg/kg
Soil skeleton	1.00						
Corg	-0.27	1.00					
pH of salt extract	-0.19	-0.19	1.00				
$P\text{-}P_2O_5$ (mg/kg)	-0.31	-0.09	0.23	1.00			
$K\text{-}K_2O$ (mg/kg)	0.25	0.04	-0.57	0.14	1.00		
NH_4^+ (mg/kg)	-0.25	-0.41	0.17	0.78	-0.05	1.00	
NO_3^- (mg/kg)	0.44	0.34	-0.16	-0.41	0.20	-0.69	1.00

Soil microstructure

The primary soils of the quarries near Urvan settlement (Figure 2 and 3) had a conventional sandy microstructure without any signs of plasma formation. The sand grains were angular fragments of quartz, mica, feldspars, and pyroclastic material (the presence of the latter is associated with the ancient volcanic activity in the North Caucasus). The average fragment size was 100-500 μm. There is no evidence of rounded mineral grains, indicating the autochthonous origin of the mineral grains in the soils. The second quarry soil features finer mineral grains, and poorly decomposed plant remains. The microstructure is characterized by a high share of porous space. The reference Leptosol between the quarries did not differ from the primary soils (Figure 4). Its mineral grain fragments were less angular, suggesting a greater transformation of the mineral content in the soil.

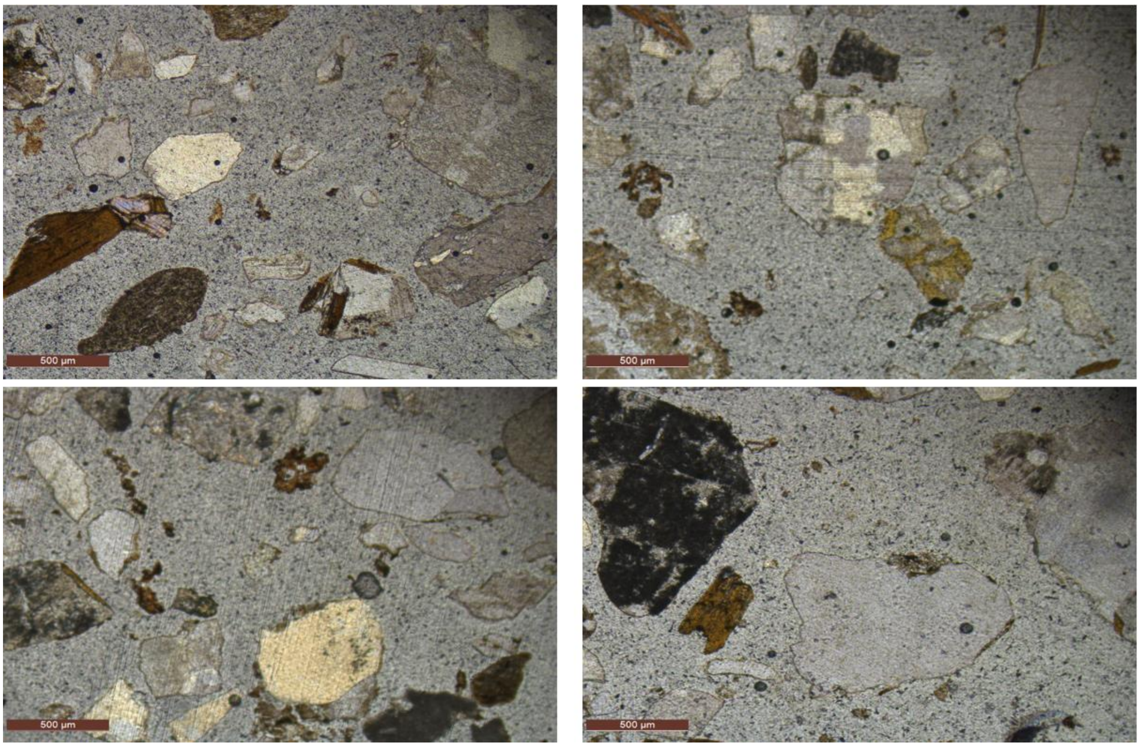

Figure 2. Overgrowing bottom of quarry No.1, near Urvan settlement, Urvan, right bank of the Urvan River.

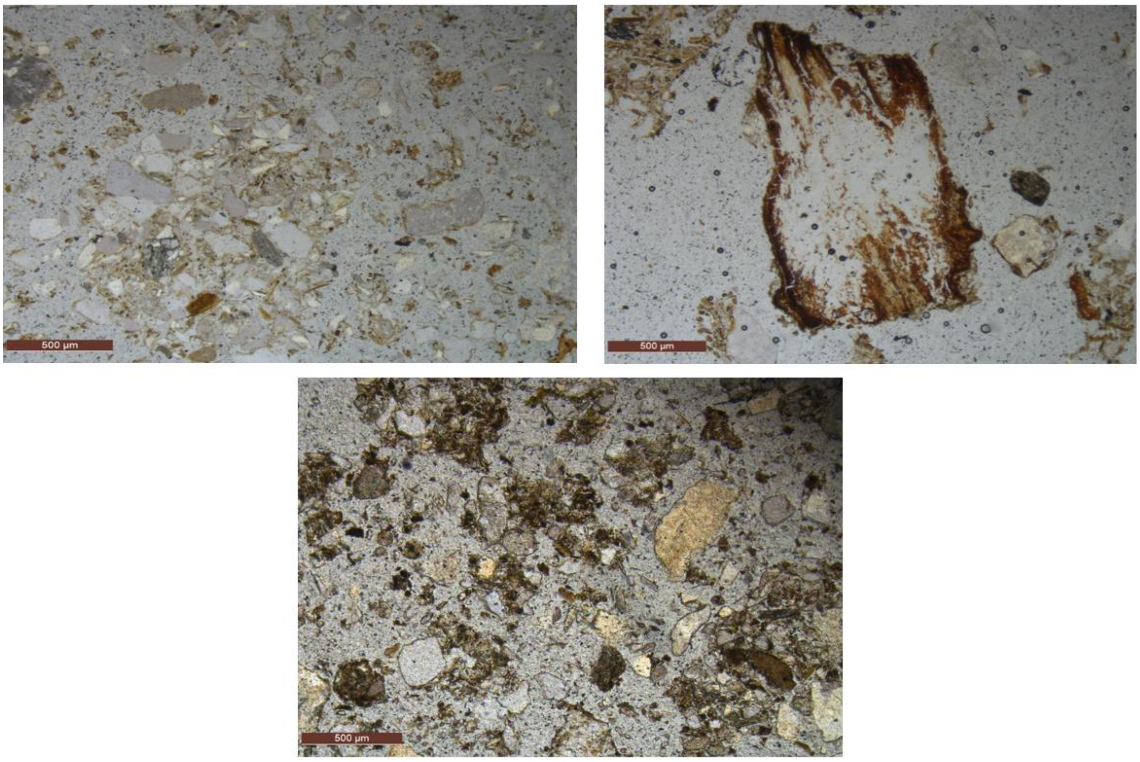

Figure 3. Overgrowing bottom of quarry No.2, near Urvan settlement, left bank of the Urvan River.

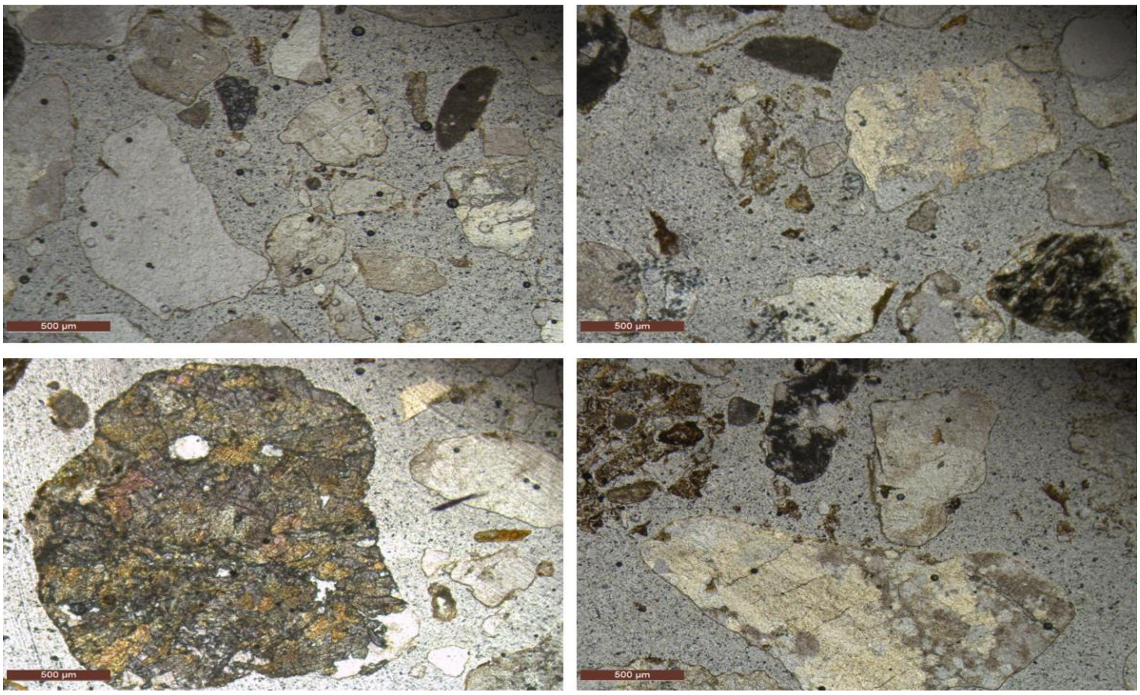

Figure 4. Reference soil, near Urvan settlement, above the wall of quarry No.1 MATURE

The primary soils in the quarry near Progress settlement were similar in that organic-mineral rounded and oval shape aggregates with irregular faces are formed in the upper horizons of these Leptosols (Figure 5,6 and 7). This was observed in all the three studied soils sampled from the quarry. The mineral grains that are not part of the aggregates are represented by angular diamond-shaped quartz grains, in which the porous spaces are extensive. In the benchmark Phaeozem soils (Figure 8) in vicinities of Progress settlement formation of aggregates is evident which is typical for this type of soils everywhere. The clay extraction quarry bottom in Gerpegezh is an underdeveloped lithosol. With a large number of roots, they are formed with rounded-cubic aggregates having a diameter exceeding 2,500 μm (Figure 9). It also contained small weakly decomposed plant residues. In the reference Umbric Retisol (Figure 10), the formation of rounded aggregates, accumulation of poorly decomposed plant residues, and loessivage of fine-grained soil in the humus-alluvial horizon were also observed.

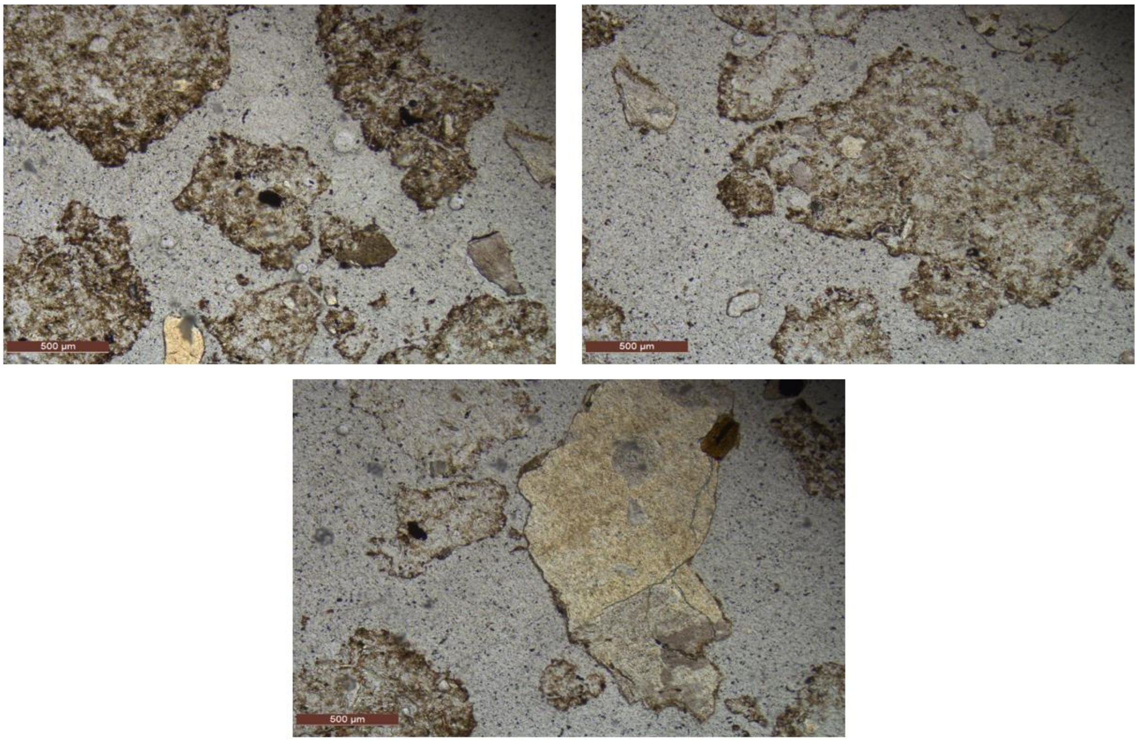

Figure 5. Bottom of quarry No. 3, grassy vegetation area, near Progress settlement.

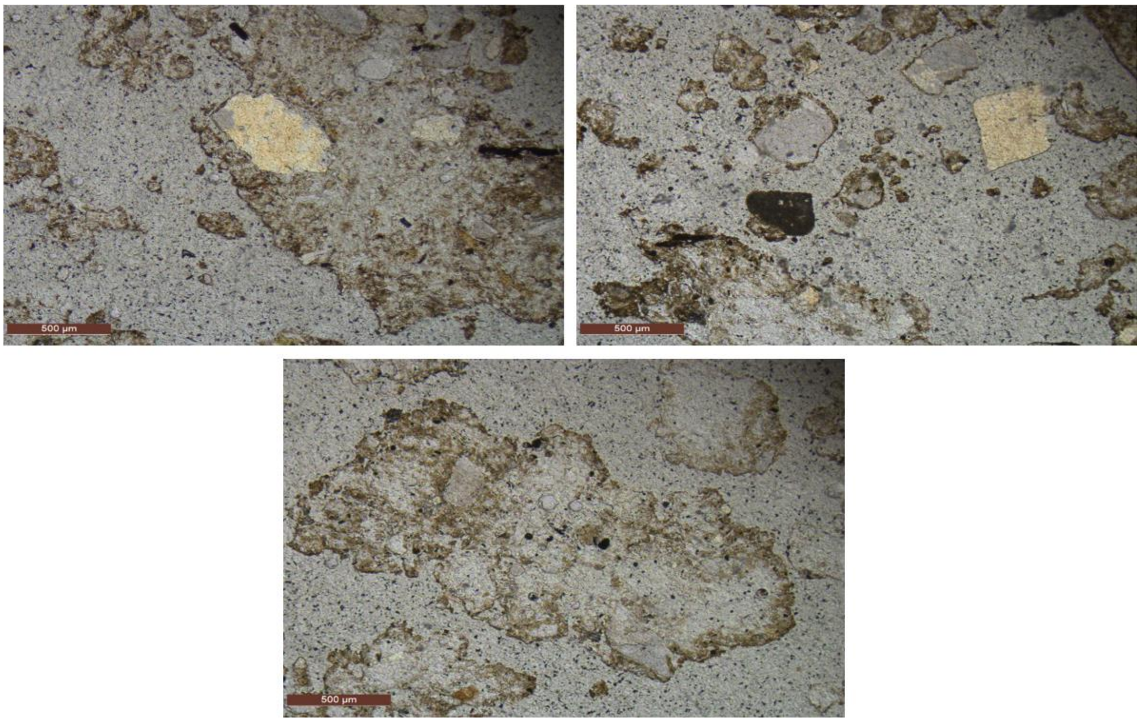

Figure 6. Bottom of quarry No. 4, the pasture area, near Progress settlement

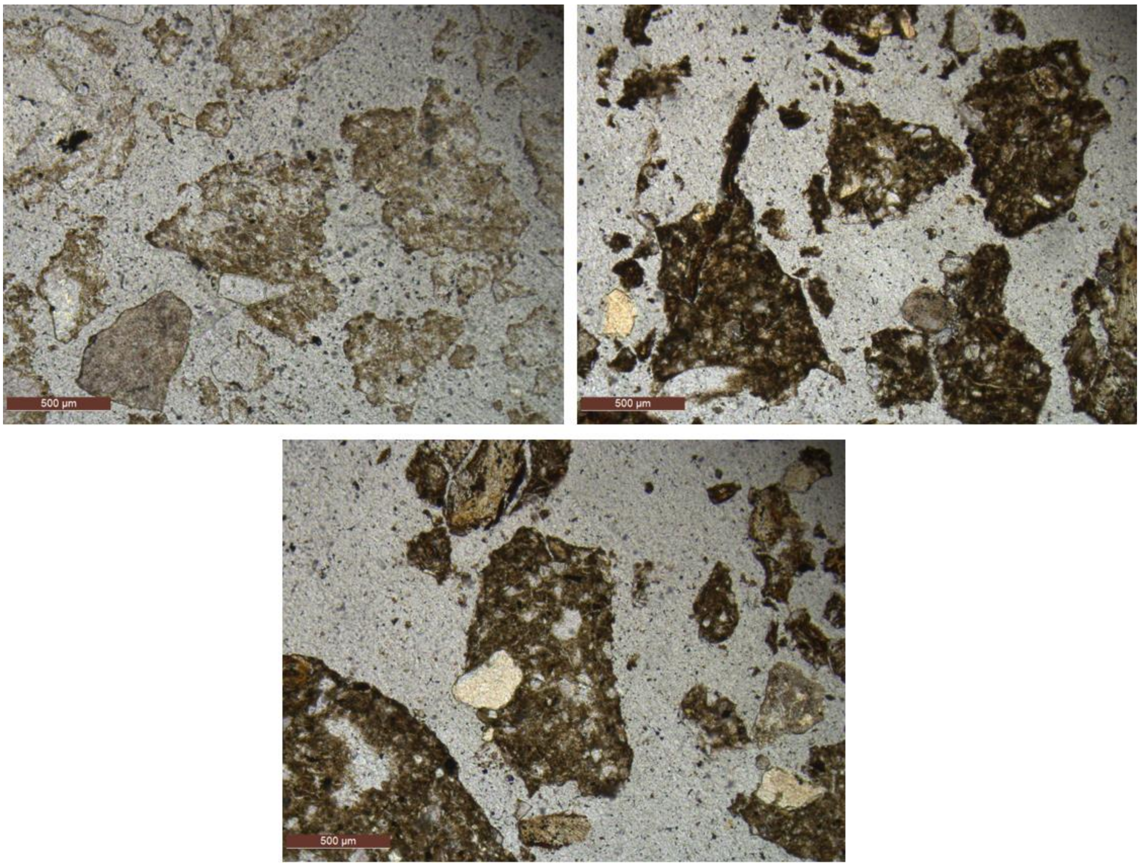

Figure 7. Bottom of quarry No. 4, area with new hillside dumps, near Progress settlement

The key factor for the primary soil formation in the quarry dumps of the studied region is the biogenic growth on the substrate, expressed primarily as the formation of rounded aggregates and the accumulation of weakly decomposed plant residues. There was almost no change in the mineral components of the primary soil. The micromorphological structure of the key local zonal soils (Phaeozems Gleic, Phaeozems and Umbric Retisols) showed that the microstructure associated with the accumulation of clastic grains of primary minerals prevails in the humus Gleysol while the microstructure of the Phaeozem and Retisol soils was controlled by biogenic transformation.

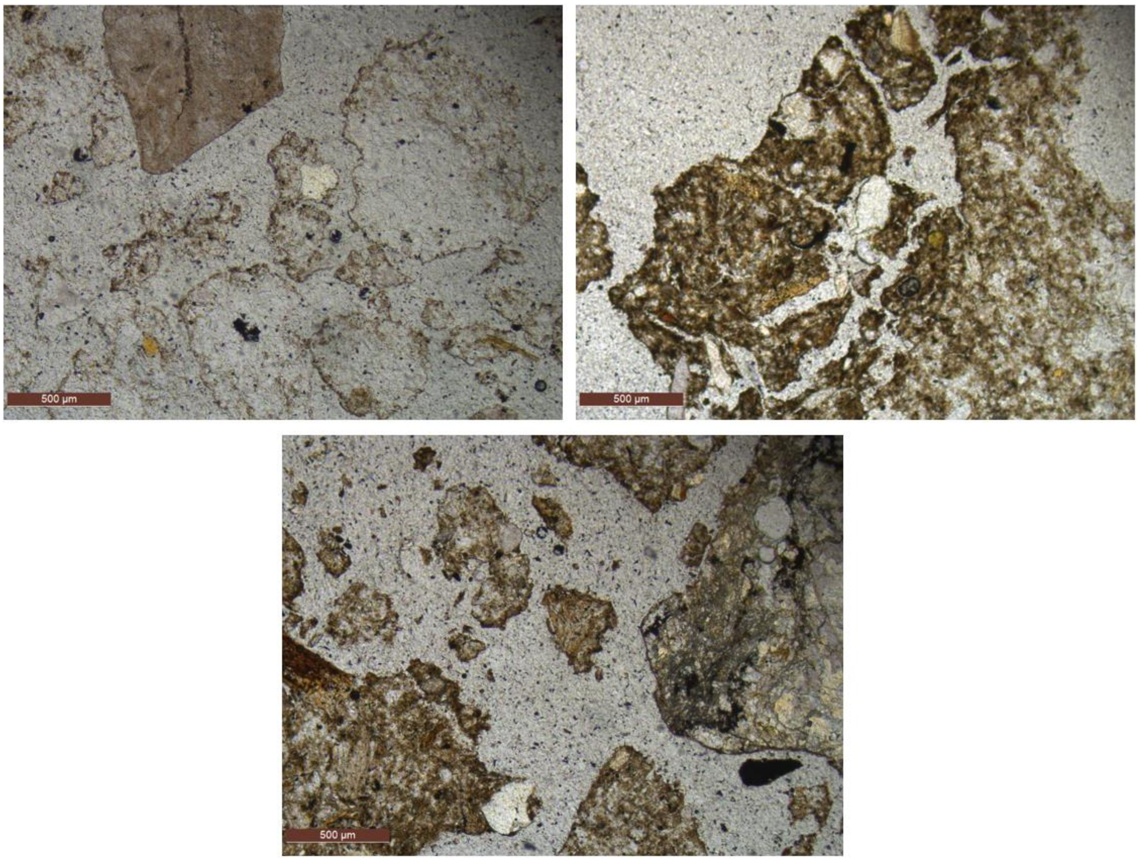

Figure 8. Reference soil, near Progress settlement, above the wall of quarry No. 3 MATURE

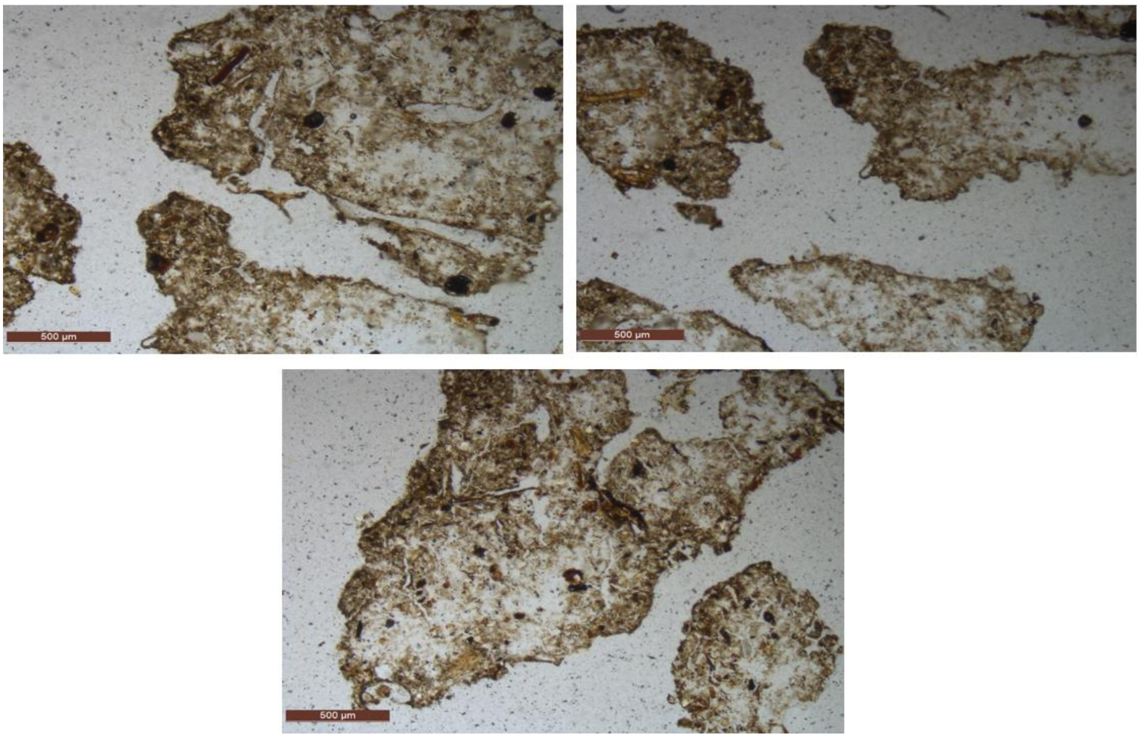

Figure 9. Overgrown bottom of quarry No. 5, near Gerpegezh settlement

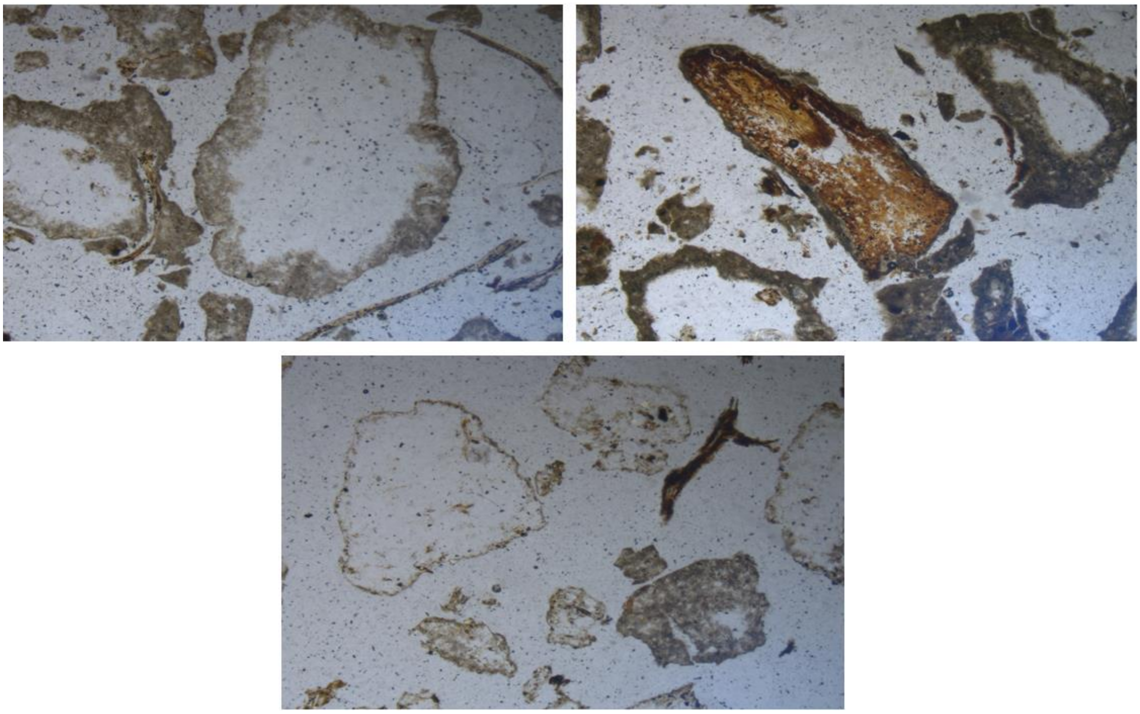

Figure 10. Reference soil, near Gerpegezh settlement, above the wall of quarry No. 5 MATURE

Discussion

Study of agrochemical properties of soils

The current study shows that the content of most measured agrochemical indicators (nutrients), was low at all sample sites. The exception was the content of K_2O, which is very high in many points, which agrees with the literature data showing that soils of the Caucasus, including the Central Caucasus, have a medium to high supply rate of mobile potassium, while in the presence of nitrogen and phosphorus they have weak and very weak supply (Novruzova, 2019; Pinskoy, 2022). The level of acidity of the background and primary soils corresponds to the genetic features of the studied soils (Gorobtsova et al., 2016b, 2017, 2021) and has a slightly alkaline and neutral reaction. The organic carbon content of the studied primary soils is characterized by relatively low values. The background soils are also characterized by a low content of organic carbon, which is typical for the soils of this region (Gorobtsova et al., 2017, 2021). The low content of organic matter in the Phaeozems sampled in Progress settlement is explained both by their genetic features and by the fact that the content of organic matter decreases in soils during their reclamation, with which other authors agree (Gedgafova et al., 2015; Liu et al., 2016). It was found that in the primary soils sampled in the clay quarry, the content of organic carbon is higher than in the background soil. This is due to the fact that the background sample, represented by Umbric Retisol, at this site was sampled under a beech-horn-horn-beech forest, under which, according to Gorobtsova et al. (2021), the humus content is low. In the primary soil, all the newly formed humus is concentrated in the superficial horizon which result in apparenly increased concentration.

The background soil in Progress settlement was the only one for which high levels of NO_3 were found and there was a predominance of NO_3 over NH_4, which is common in some agricultural soils (Cui and Song, 2007). This can be explained that clay particles and organic matter of acid soils called also as colloidal materials include positive ions due to variable charges and NO3 ions include negative charge so acid soils have high NO3 level. This may be due to soil acidity, nitrate leaching, or the application of crop residues after harvesting has ceased (Dejoux et al., 2000; Miller and Kramer, 2004). Soil agrochemical analyses have shown, that soil restoration is not limited by nutrient content, at least the nutrient content is not a critical factor for self-overgrowing pits and soil regeneration.

Study of micromorphological properties of soils

Previous micromorphological studies of soils in the Caucasus have focused on issues such as the study of deep soil processes in ancient mounds (Alexandrovskiy et al., 2014), organic matter distribution processes (Kovda et al., 2010), and the study of the micromorphology of cryoconite, which showed the presence of a silty fraction with a predominance of grains with smooth edges (Zavierucha et al., 2019). They found that local geomorphology and features of geology are more important than regional climate in shaping soil micromorphology. Our work was the first to investigate the micromorphological organization of the main zonal soils of the Central Caucasus - Phaeozem Gleic. Phaeozems and Umbric retisol and primary soils of quarry-dump complexes. The formation of a humus-clay plasma was revealed in the Phaeozem soil, which is characteristic of zonal soils of the accumulative-humus series (Gerasimova et al., 1992). Our study has shown that in Phaoeozem Gleyic soils, microstructure dominates, associated with the accumulation of angular grains of primary minerals, while in Phaeozem and Retisol, microstructure is caused mainly by biogenic processes of structure transformation.

The received data have shown that the main factor of initiation of primary soil formation on dumping pits of Central Caucasus is biogenic alteration of a substrate, expressed, first of all, in formation of rounded aggregates and accumulation of weakly decomposed vegetative residues. It is revealed that the change in the mineral part of the soils in the primary soils is practically not observed, indicating that the biogenic-abiogenic interactions in the soils are at the very initial stage. This is typical feature of microstructure of primary soils of dry region if one compare they with initial soils of boreal environments (Abakumov and Gagarina, 2006). Thus in norther soils weathering rate and degree of mineral part alteration is higher due to higher water saturation rate and accumulation of organic acids, derived from organic remnants of coniferous forests. Thus, self regeneration of soil could evaluates as slower process in quarries steppe region if one compare with boreal ones.

While Figures 2-10 shows photos of soils in transmitted light, which allows us to analyze the shape of grains and structure, Fig. 11 shows photos in transmitted light and crossed nicols (Stoops, 1986) which is important for analyses of mineralogical soil features. Fists pair of photo demonstrates oligomineral grains with dominance of quarts, which changes color from white-grayish in transmitted light to blue in crossed nicols. This and angular form of grains is typical for primary soils and indicates that weathering is only on very initial stages (Abakumov et al., 2005). Another feature is that mica presented on surfaces of grains, mica is unstable for weathering and its being in soils indicates very initial alterations stages of soil materials transformation (Abakumov et al., 2022). Thus, the soil of Urvan quarry demonstrates very initial stage of mineral part alteration. Leptosol of the bottom of Progress quarry demonstrate very intensive aggregation of soil matter – sandy particles are glued by clay and humus, which indicates intensive biogenic-abiogenic interaction (Figure 11). Nevertheless, the reference Phaeozem demonstrates higher intensity of aggregate formation and larger diameter of structural units (Figure 11), which is typical for zonal Chernozems of Caucasus region.

Conclusion

The soils from the quarries of the Central Caucasus were compared with the reference soils from the adjacent territories. The significant differences in the organic carbon content of the primary and reference soils for the areas near Urvan and Progress settlements. In contrast, the Gerpegezh site showed no differences for organic carbon content but acid and alkaline properties. For all other studied chemical properties, no significant differences between the primary and reference soils in the areas studied were found. The results indicates that the primary soil formation in the surveyed areas is close to zonal formation in terms of chemical properties. The micromorphological data shows that the soils of Progress and Gerpegezh settlements contain biogenic round-cubic aggregates and some humus-clay plasma components. In general, non-toxic waste rocks in the studied areas are subjected to fairly rapid overgrowth, which leads to the manifestation of biogenic accumulative processes and the formation of primary soils with attributes (including micromorphological properties) close to that of the Leptosols in the primary soils. Low intensity of in situ soil weathering and appearance of few micro feautres of biogenic-abiogenic interaction in primary soils in spite of good nutrient state indicates that climate is key limiting factor of initial soil development.

For the first time in the Central Caucasus, a micromorphological and agrochemical study of the soils of abandoned quarries was carried out, in comparison with reference soils. In this work, abandoned clay, sand and gravel quarries were examined, although there are also other quarries in the Central Caucasus - stone, brick and tile quarries, loam, volcanic ash and pumice, tuff, limestone, granite, gypsum, sand and bentonite deposits, where no such studies have been conducted so far. All of the above, makes the continuation of the study of morphological. micromorphological and agrochemical properties of abandoned quarries in the Central Caucasus especially relevant.

Acknowledgements

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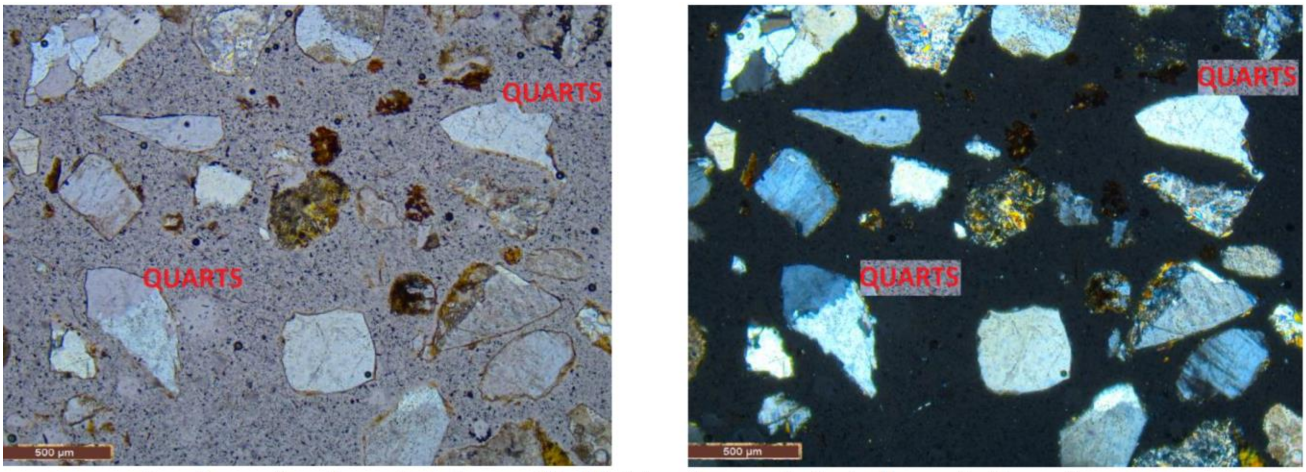
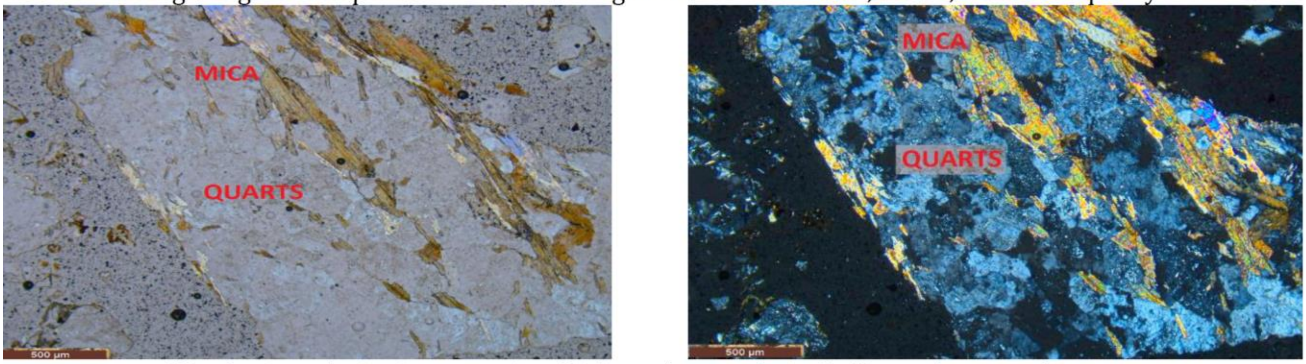
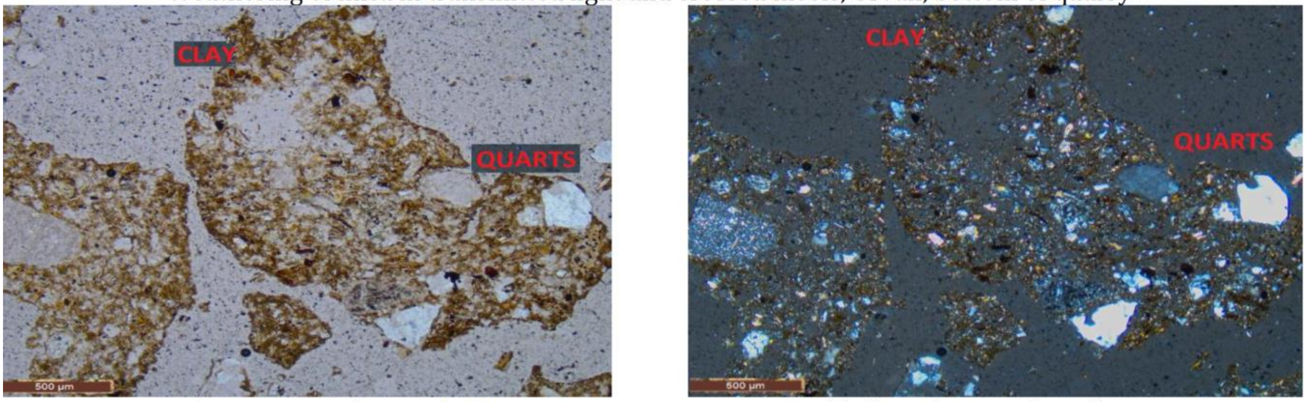


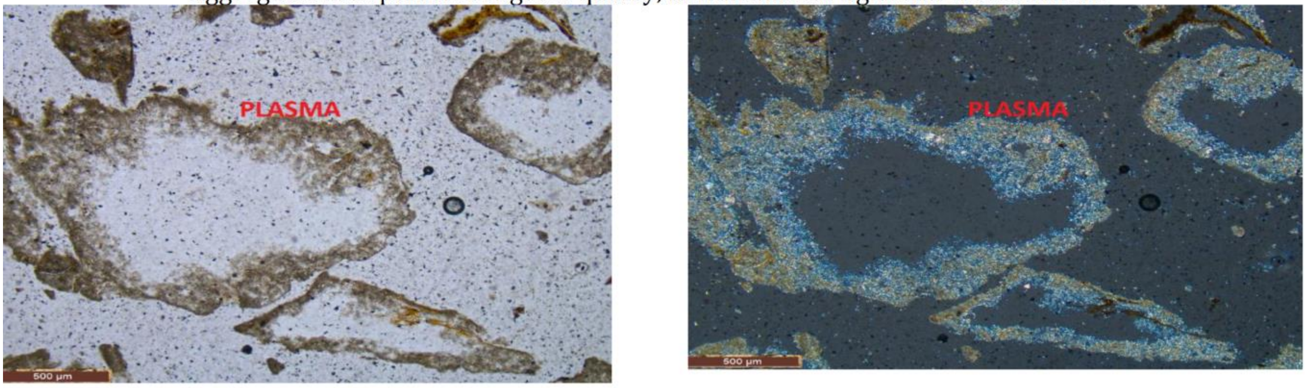
Angular grains of quarts in transmitted light and crossed nicols, Urvan, bottom of quarry



Weathering of mica in transmitted light and crossed nicols, Urvan, bottom of quarry



Aggregates in Leptosols Progrees quarry, in transmitted light and crossed nicols



Aggregates in superficial Phaeozem layer, in transmitted light and crossed nicols
Figure 11. Soil sections in transmitted light (left) and in crossed nicols (right)

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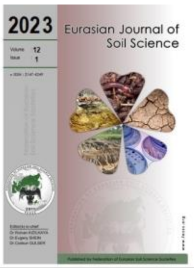

The determination of grain yield, yield components, and macro nutrient content of corn (*Zea Mays* L.) by different agricultural practices

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Abstract

A field experiment was conducted to determine the impacts of some treatments on grain yield, yield components (cob length, cob diameter, grain weight), and macro nutrient content of corn (*Zea mays* L.). During the study, tobacco waste compost (50 t ha^{-1}), poultry manure (4 t ha^{-1}), bio-humus (10 t ha^{-1}) and NPK (0.3 t ha^{-1}) were applied. The experiment was established with a randomized complete block design with four replications in Izmir, Türkiye. According to the two years average values; cob length varied from 18.84 to 22.35 cm, cob diameter from 4.38 to 5.05 cm, grain weight from 1704 to 2529 g, grain yield from 14.48 to 19.88 t ha^{-1} by the treatments. The greatest average yield values were obtained under tobacco waste compost (19.88 t ha^{-1}) and poultry manure (19.64 t ha^{-1}) plots over the control. All yield components were significantly affected the treatments. Macro nutrient contents of corn grain were found statistically significant by the treatments as compared with control. Total N, P, K, Ca, and Mg content of grain varied between 1.25-1.64%, 0.044-0.087%, 2103-3559 ppm, 25.83-571.88 ppm, 127.57-469.93 ppm, respectively. As a conclusion, all treatments increased the yield components and macro nutrient content of corn with similar effects; on the other hand, poultry manure and tobacco waste compost were the most effective materials on all parameters. Moreover, the positive and significant correlations were found among first and second year parameters.

Keywords: Bio-humus, corn, NPK, poultry manure, tobacco waste compost, yield.

Introduction

Corn (*Zea mays* L.) is one of the most important cereals that provides staple food for human population in the world. However, it is a tropical crop, at present its cultivation in subtropical and temperate regions is also done intensively on World wide bases and it can successfully be cultivated twice in a year. Approximetly 61% of world corn production is used as animal feed, 19% as ethanol and other industrial products, 15% as direct human food, 4% as storage losses and 1% as seeds (Garcia-Lara and Sena-Saldivar, 2019). Corn is a major source of income for many farmers in developing countries (Tagne et al., 2008). In Türkiye, corn ranks third after wheat and barley in terms of cultivation and production and first among all cereals in terms of yield (Ozaslan and Kusaksiz, 2021). Total planting area, production of corn and yield were about 758 237 ha, 6 750 000 t, and 89 kg ha^{-1} in 2021, respectively in Türkiye (TUIK, 2022). Production of corn crop is carried out mostly in Marmara in North Western, Aegean in Western and Mediterranean in Southern regions of Turkey (Tonk et al., 2011).

Corn varieties vary according to their growth properties, yield and components, and hence suggested that breeders should choose most promising combiners in their breeding program (Odeleye and Odeleye, 2001). Manures and mineral fertilizers contributes approximetly 50 to 60% increase in productivity of food grains in many parts of the world, exclusive of soil and agro-ecological zone (Shakoor et al., 2015).

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The adequate amounts of manure needed to be apply to the soils in a proper way to meet the nutrient need of the crop and maintenance of soil quality. The organic wastes will increase the effciency use of nutrients added by mineral fertilizers by decreasing losses and improving availability of nutrients to the crop (Tolessa et al., 2001). It is reported that mineral fertilizer is known to affect the quantity and yield of corn (Ayodele, 1993).

Poultry manure alone and in combination with mineral fertilizer can be used for nutrient supplementation (Rasheed et al., 2003). Organic manure promotes seed germination and root growth by improving soil water holding capacity and maintain better aeration. Corn production can be improved significantly with the addition of farmyard manure alone and with conventional fertilizer (Sharma and Gupta, 1998). Stefan (2003) reported that fresh poultry manure contains 70% water, 1.4% N, 1.1% P_2O_5 and 0.5% K_2O while dried poultry manure contains 13% water, 3.6% N, 3.5% P_2O_5 and 1.6% K_2O.

Compost can alter soil physical and biological properties in ways that can influence crop performance. Soil moisture (Serra-Wittling et al., 1996) and thermal properties (Jacobowitz and Steenhuis, 1984) can be improved by compost applications. Besides, it can improve soil microbial activity and biomass (Fraser et al., 1988), by decreasing the incidence and severity of crop diseases through stimulation of antagonists (Craft and Nelson, 1996) and decreasing in substrate availability (Mandelbaum and Hadar, 1990). Tobacco wastes are generated at various stages of post-harvest processing of tobacco and during the manufacture of tobacco products (Adediran et al., 2004). These wastes (*Nicotiana tabacum*) are phytotoxic due to their high content of alkaloids which if not well-managed can cause environmental damage (Adediran et al., 2003; Mumba and Phiri, 2008). Composting of these wastes can reduce the alkaloid content and convert them into useful materials (Adediran et al., 2004; Okur et al., 2008; Cercioglu et al., 2012; Nguyen et al., 2022). Organic wastes such as manures, composts and plant residuals are frequently used in crop production systems as an alternative to mineral fertilizers, to restore degraded soils and ameliorate physicochemical constraint (Celestina et al., 2019). The addition of plant residuals into the soil is considered a good management practice since it stimulates soil microbial growth and activity, with the subsequent mineralization of plant nutrients and improves soil fertility and quality (Doran et al., 1988; Eriksen, 2005; Randhawa et al., 2005; Cercioglu, 2017).

The purpose of this study was to examine the impacts of some agricultural practices (bio-humus, poultry manure, tobacco waste compost and NPK fertilizer) on grain yield, yield components and macro nutritional composition of corn.

Material and Methods

Study Site and Treatments

The study site was located at the Menemen Research and Practice Farm of Ege University in Izmir, Turkey (38°58′ N, 27°03′ E). Long-term average annual precipitation and temperature in Izmir is 713.8 mm and 17.9℃ respectively (Meteroloji Genel Müdürlüğü, 2022). Some climatic data for Menemen was given in Table 1. The soil was classified as sandy loam (*Typic Xerofluevent)* (Soil Survey Staff, 2006) and some initial soil properties were shown in Table 2. A 2-year field experiment was conducted in a randomized complete block design with four replicates per treatment. The four types of amendments used were: poultry manure, tobacco waste, bio-humus and NPK fertilizer. Some properties of these amendments were given in Table 3. Tobacco wastes were gathered from cigarette industry and composting process was performed outdoor under a roof. The moisture content of the compost was determined approximetly 55% by weighing the material regularly and adding water when necessary. Aeration was made by manual turning during the composting period. After 3 months, when the temperature of the compost decreased to the ambient level, composting was completed. Both of bio-humus (composted plant residues) and poultry manure were obtained from organic manure industry for this study. All organic materials were added into the soil one day before planting and their doses were determined by researching recent studies, recommendations from producers of materials and plant nutrient removal by corn from soil. Application doses were as follows: poultry manure: 4 t ha^{-1}, bio-humus: 10 t ha^{-1}, NPK: 0.3 t ha^{-1}, tobacco waste compost: 50 t ha^{-1}. Bio-humus and poultry manure were both added to the soil with NPK. Triple superphosphate (43-44% P_2O_5), ammonium nitrate (33% N), and ammonium sulphate (21% N) were applied as NPK fertilizers with the doses of 19 kg da^{-1} N, 9 kg da^{-1} P_2O_5 and 21 kg da^{-1} K_2O.

The total amount of water required by corn was supplied in each year was 600 mm (600 m^3 da^{-1}) through drip irrigation considering rainfall events. Some quality parameters of irrigation water used in the experiment was shown in Table 4. Kermess variety of corn (*Zea mays* L.) was used as a test crop in the experiment. The corn seeds were planted in April with 0.70 × 0.18 m spacing and harvested in October for both years. Grain yield, yield components (cob length, cob diameter, grain weight) and macro nutritional composition (N, P, K, Ca, Mg) of corn were examined.

Table 1. Some meteorological data of study site (MEVBİS, 2022).

	Total rainfall (mm)	
Months	1st year	2nd year
January	154.4	97.2
February	114.0	211.0
March	131.8	21.6
April	46.6	51.0
May	9.6	23.4
June	7.6	16.6
July	0.0	7.0
August	0.0	0.0
September	34.8	28.0
October	17.0	287.6
November	70.0	19.6
December	165.8	144.8
Total	751.6	907.8
	Mean temperature (°C)	
Months	1st year	2nd year
January	9.0	9.5
February	9.3	11.7
March	10.5	11.7
April	15.1	15.7
May	20.4	20.5
June	25.2	24.1
July	27.9	27.6
August	27.0	28.6
September	22.4	22.9
October	19.6	17.3
November	13.3	16.8
December	11.7	11.9
Mean	17.7	18.2

Table 2. Some soil properties of the study site

Parameters	
Sand,%	55.28
Silt, %	36.00
Clay, %	8.72
pH	7.78
OM, %	1.11
EC, µS cm^{-1}	72.00
$CaCO_3$, %	4.70
Total N, %	0.07

Table 3. Some properties of the amendments

	Poultry manure	Tobacco waste compost	Bio-humus
pH	8.60	9.18	7.88
EC, dS m^{-1}	54.50	49.50	9.20
OM, %	44.90	33.60	46.50
$CaCO_3$,%	12.00	7.06	26.00
N, %	1.01	0.87	0.92
P, %	0.34	0.27	0.20
K, %	2.19	1.94	0.69
Ca, %	9.44	7.44	11.76
Mg, %	1.20	0.63	0.92

Table 4. Quality properties of irrigation water

Parameters	
pH	7.22
EC (µS cm^{-1})	1000
Cations (me L^{-1})	
Na	3.37
K	0.03
Ca+Mg	6.60
Anions (me L^{-1})	
Cl	2.92
CO_3	-
HCO_3	6.40
SO_4	0.64
SAR	1.85
Quality Class	C3S1

Soil Sampling and Laboratory Analyses

Soil samples were removed from 0-30 cm depth of the center of each plot. These samples were air-dried and passed through a 2 mm sieve prior to analysis. Soil texture was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Organic matter concentration was analyzed according to Nelson and Sommer (1982). Calcium carbonate content was analyzed according to the Scheibler method (Tüzüner, 1990). Soil pH (Jackson, 1967), electrical conductivity (Rhoades et al., 1999), total N (Bremner, 1965) were determined. The pH and EC measurements for organic wastes were performed in aqueous extract by using pH and EC meter. The samples were obtained by mechanically shaking with distilled water for 1 hour at a 1/10 solid/water ratio (dry weight/volume) (Kacar, 1994).

Corn grains were ground and wet digested by a HNO_3 + $HClO_4$ mixture. Total N content was measured by Kjeldahl method (Tan, 2005). Total P values were analyzed by vanadomolybdophoshoric method (Lott et al., 1956). Total K, Ca, and Mg contents were determined by atomic absorption spectrofotometry (Hanlon, 1998). Yield values were determined by collecting 10 crops from each plot and calculated by measuring total weight, cob weight, and grain weight in t ha^{-1}.

Statistical Analysis

An analysis of variance (ANOVA) was conducted using the GLM procedure with SPSS 25.0 to examine the impacts of agriculture practices over years on cob components and nutritional composition of crop. Statistical differences were evaluated with Tukey's test of means at an alpha level of 0.05 using SPSS 25.0 (SPSS, 2021). Moreover, correlation tests were performed between first and second year parameters.

Results and Discussion

Grain yield and yield components of corn

The effects of poultry manure, bio-humus, NPK and tobacco waste compost on yield and yield components of corn were shown in Table 5. Grain weight values were significantly affected by the treatments for both years as compared to control. Grain weight values varied among 1094 g and 3051 g and the greater average results were determined under tobacco waste compost and poultry manure treatments. Grain yield values significantly varied among 11.79 and 24.01 t ha^{-1} by the treatments. All materials significantly increased grain yield values as compared to control. The greater yield values were analyzed in the first year as 24.01 t ha^{-1} and 23.85 t ha^{-1} by the treatments of poultry manure and tobacco waste compost, respectively. Yield results decreased in second vegetation period as the extremely dryness of the second year (see Table 1). Although there is sufficient moisture in the soil, the decrease in temperature restricts plant growth. The restriction of plant growth with summer drought and the storage of moisture in the winter period and providing suitable humidity during plant development indicate the Xeric humidity regime (Basayigit and Dinc, 2005). Ayoola and Makinde (2009) were found higher grain yield of corn under poultry manure plots and lower in NPK fertilizer and control plots. Mix application of poultry manure and NPK fertilizers can improve the efficiency of nutrient uptake and availability to the crop (Warren et al., 2006).

The point is about poultry manure has very high salinity content. Because of this problem, using poultry manure in the studies may cause some problems. Hence, it is needed to be measure of salinity content before applying to the soil. Moreover, the addition of tobacco wastes on soil were improved yield in various crops by many researchers (Özgüven and Kaya, 1984; Durak and Brohi, 1986; Brohi, 1987; Brohi and Durak, 1988;

Sayın and Aydın, 1989; Özgüven et al., 1999). The present study results were found similar with these literatures about corn yield.

Cob length is related to number of grains per cob and the factors reducing number of grains per cob also reduced cob length. Cob length is an important yield factor that is positively related to grain yield and has high heritability (Ruiz de Galarreta and Alvarez, 2001; Lucchin et al., 2003). Additionally, cob length is also affected by genetic structure, environmental factors, cultivation techniques such as planting time, plant density and nitrogen dose. Cob length results were significantly affected by the treatments when compared with control ($p<0.05$). Average values for cob length varied among 18.84 cm and 22.35 cm. All the treatments were showed same significance levels as compared to control. Oktem and Kahramanoglu (2021) were conducted an experiment to obtain grain yield and quality parameters of some popcorn genotypes. They found that cob length values were ranged from 17.68 to 22.95 cm. Ozturk and Buyukgoz (2021) were carried out a study to evaluate agronomic performance of some corn landraces in Trabzon. They used 18 corn landraces and two certified corn varieties. According to their findings; cob length values varied between 10.85 and 21.95 cm.

Cob diameter affects the grain yield by changing the number of grain rows and the number of grains in the cob; it is known to vary according to genotype, environmental conditions and cultural practices. Cob diamater values varied among 4.07 cm and 5.73 cm. The greater values were found as 5.73 cm by poultry manure treatment in the first year. On the other hand, the higher cob diameter values were determined as 4.84 under tobacco waste compost plots in the second year. In Trabzon, a study was performed to determine agronomic performance of some corn landraces. 18 corn landraces and two certified corn varieties were used and cob diameter values varied from 3.34 cm to 4.71 cm (Ozturk and Buyukgoz, 2021). Oktem and Kahramanoglu (2021) were conducted a research on some popcorn genotypes and measured yield and quality parameters. According to their findings, cob diameter of corns was varied among 2.99 cm and 3.76 cm. Özkaynak and Samancı (2003) reported the cob diameter values of corn varied among 2.40 cm and 2.90 cm in lines, 2.60 cm and 3 cm in hybrids. Similar results were also found by other researchers (3.30-4.40 cm, Tekkanat and Soylu, 2005; 2.97-3.39 cm, Özkan, 2007; 2.83-3.06 cm, İdikut et al., 2012; 2.67-3.01 cm, Cihangir, 2013).

Macro nutrient concentration of corn grain

Macro nutrient contents of corn grain were significantly affected by the treatments as shown in Table 6 and Table 7. Total N concentration of grain ranged from 1.25 to 1.64% by the treatments. The highest total N content was found in the first harvest under poultry manure treatment by the increasing rate of 22.4% as compared to control. Bio-humus and tobacco waste compost treatments showed same significance level on N content of grain. In the second year of the experiment, total N content was determined significantly greater under poultry manure, bio-humus and tobacco waste compost by same significance level when compared to control. According to the average N values of first and second harvest; significantly greater values were found by poultry manure treatment. P contents of corn grain varied among 0.044 and 0.087% by the treatments with significant differences. The greatest P values were analyzed in the first year under NPK treatment by the increasing rate of (approximetly) 32% as compared with control. In the second year, P values were found significantly higher under poultry manure, NPK, and tobacco waste compost plots by same significance level. The average higher P values of first and second harvest crops were observed by NPK treatment as compared to control. K contents of corn grain were significantly affected by the treatments and it varied from 2103 ppm to 3559 ppm. The greater K values were determined under tobacco waste compost as compared to control in the first and second year experiment. Tobacco waste compost was showed significantly 57% greater K values than control in the first year. Ca content of corn grain significantly varied among 25.83 and 571.88 ppm by the treatments. The highest Ca values were determined by tobacco waste compost in the first harvest as compared to control. After second harvest, the greatest Ca values were found under bio-humus treatment. According to the average values, the higher Ca results were analyzed by the application of tobacco waste compost. Mg content of corn grain significantly varied among 127.57 and 469.93 ppm by all the treatments. The greatest Mg values (469.93 ppm) was found under poultry manure plot in the first year of the experiment. Dogan et al. (2019) observed that the lowest Mg from the plots without fertilizer, and the highest Mg value was obtained from the plots with poultry manure, farmyard manure and mineral fertilizers. Jackson (1999) determined that poultry manure increases the water soluble and exchangeable K and Mg which enhances crop yield. Ojeniyi and Adeniyan (1999) reported that poultry manure can effectively increase soil fertility, yield, and nutritional composition of crops.

Table 5. Mean comparison of different treatments on grain yield and yield parameters

	Grain weight (g)			Grain yield (t ha^{-1})			Cob length (cm)			Cob diameter (cm)		
Treatments	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Control	2314 c	1094 d	1704 d	17.18 c	11.79 c	14.48 c	20.25 b	17.42 d	18.84 c	4.69 c	4.07 c	4.38 d
Poultry manure+NPK	3051 a	1959 b	2505 a	24.01 a	15.28 ab	19.64 a	22.77 a	20.05 b	21.41 b	5.73 a	4.38 b	5.05 a
Bio-humus+NPK	2676 b	1760 c	2218 b	21.43 b	13.03 bc	17.23 b	23.80 a	19.11 c	21.46 b	4.91 b	4.42 b	4.67 c
NPK	2520 c	1684 c	2102 c	20.83 b	12.99 bc	16.91 b	23.24 a	19.05 c	21.15 b	4.89 b	4.35 b	4.62 c
Tobacco waste compost	3012 a	2046 a	2529 a	23.85 a	15.91 a	19.88 a	23.73 a	20.97 a	22.35 a	4.83 bc	4.84 a	4.83 b
Mean	2715	1709	2212	21.46	13.80	17.63	22.76	19.32	21.04	5.01	4.41	4.71
CV (%)	11.67	21.85	15.27	12.96	12.51	12.59	6.42	6.84	6.23	8.21	6.26	5.29
F value												
Year			72.964*			317.567*			121.096*			96.378*
Treatment	159.46*	192.34*	1.561	39.98*	4.08*	21.326*	10.18*	23.90*	1.744	60.09*	15.14*	2.200
Year*Treatment			0.915			1.883			1.907			2.201

The table presents significance levels between treatments for the measured parameters. Within columns, values followed by same letter for the treatments are not significantly different at $p<0.05$ probability level (Poultry manure: 4 t ha^{-1}, Bio-humus: 10 t ha^{-1}, NPK: 0.3 t ha^{-1}, Tobacco waste compost: 50 t ha^{-1}). *=Significant at $p < 0.05$.

Table 6. Mean comparison of different treatments on N, P, K content of grain

	N (%)			P (%)			K (ppm)		
Treatments	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
Control	1.34 d	1.25 d	1.29 d	0.066 c	0.044 c	0.055 d	2262 d	2103 d	2182 d
Poultry manure+NPK	1.64 a	1.50 a	1.57 a	0.078 b	0.067 a	0.072 bc	2928 b	2625 b	2777 b
Bio-humus+NPK	1.55 b	1.49 a	1.52 b	0.079 b	0.063 b	0.071 c	2585 c	2473 c	2529 c
NPK	1.43 c	1.34 b	1.38 c	0.087 a	0.068 a	0.077 a	2819 b	2646 b	2733 b
Tobacco waste compost	1.56 b	1.52 a	1.54 ab	0.080 b	0.068 a	0.074 b	3559 a	3110 a	3335 a
Mean	1.50	1.42	1.46	0.078	0.062	0.0698	2830.6	2591.4	2711.2
CV (%)	7.88	8.38	8.20	9.72	16.57	12.30	16.98	13.99	15.51
F value									
Year			43.64*			359.56*			49.35*
Treatment	53.40*	30.81*	76.15*	36.81*	56.55*	88.90*	60.08*	67.56*	121.93*
Year*Treatment			1.88			6.30*			3.26

The table presents significance levels between treatments for the measured parameters. Within columns, values followed by same letter for the treatments are not significantly different at $p<0.05$ probability level. (Poultry manure: 4 t ha^{-1}, Bio-humus: 10 t ha^{-1}, NPK: 0.3 t ha^{-1}, Tobacco waste compost: 50 t ha^{-1}). *=Significant at $p < 0.05$.

Table 7. Mean comparison of different treatments on Ca and Mg content of grain

	Ca (ppm)			Mg (ppm)		
Treatments	1st year	2nd year	Mean	1st year	2nd year	Mean
Control	376.25 c	25.83 d	201.04 d	155.28 d	127.57 d	141.43 e
Poultry manure+NPK	506.25 b	86.02 b	296.13 b	469.93 a	199.37 a	334.65 a
Bio-humus+NPK	470.94 b	109. 67 a	290. 30 b	377.84 b	174.10 b	275.97 b
NPK	468.75 b	51.83 c	260.30 c	283.50 c	157.31 c	220.40 d
Tobacco waste compost	571.88 a	83.36 b	327.60 a	370.62 b	156.06 c	263.34 c
Mean	478.81	71.34	275.07	331.43	162.88	247.16
CV (%)	14.80	45.86	17.37	35.76	16.19	29.06
F value						
Year			4274.8*			1889.6*
Treatment	29.12*	49.44*	47.05*	219.5*	62.28*	274.6*
Year*Treatment			15.72*			117.7*

The table presents significance levels between treatments for the measured parameters. Within columns, values followed by same letter for the treatments are not significantly different at $p< 0.05$. (Poultry manure: 4 t ha^{-1}, Bio-humus: 10 t ha^{-1}, NPK: 0.3 t ha^{-1}, Tobacco waste compost: 50 t ha^{-1}). *=Significant at $p < 0.05$.

Correlation of first and second year parameters

Correlation is a parameter that shows strenght or weakness relationships between variables. In the study, correlation among average yield parameters and macro nutrient content of corn was given in Table 8. The correlation between all parameters was positive and significant at 1% level. The greatest correlation coefficient (r=0.939**) was determined between grain weight and grain yield. Grain weight per cob is the main factor, which contributes substantially towards final yield per hectare (Cheema et al., 2010).

Table 8. Correlation among average (first and second year) yield parameters and macro nutrients of corn

	Grain weight (g)	Grain yield (t ha^{-1})	Cob length (cm)	Cob diamater (cm)	N (%)	P (%)	K (ppm)	Ca (ppm)	Mg (ppm)
Grain weight (g)	-	0.939**	0.883**	0.831**	0.723**	0.835**	0.645**	0.916**	0.869**
Grain yield (t ha^{-1})			0.875**	0.796**	0.655**	0.765**	0.600**	0.912**	0.884**
Cob length (cm)				0.723**	0.656**	0.856**	0.621**	0.844**	0.812**
Cob diameter (cm)					0.688**	0.657**	0.491**	0.709**	0.806**
N (%)						0.607**	0.635**	0.488**	0.735**
P (%)							0.631**	0.754**	0.693**
K (ppm)								0.469**	0.522**
Ca (ppm)									0.828**
Mg (ppm)									-

**=Significant at $p<0.01$

Conclusion

Results of present study indicated that all treatments had greatly affected grain yield, yield components and macro nutritional composition of corn for both years. The most significant impact was observed when tobacco waste compost and poultry manure was applied to soil. All yield component values were significantly affected by the treatments. The average cob diameter values were higher under poultry manure, cob length values were higher under tobacco waste compost, grain weight values were higher under poultry manure and tobacco waste compost treatments. The average grain yield results were obtained significantly greater under tobacco waste compost and poultry manure than control plot. Total average N, P, K, Ca, and Mg content of grain were significantly affected by tobacco waste and poultry manure treatments. Correlations between grain yield to, grain weight, cob length, and cob diameter were positive and significant.

It is concluded that tobacco waste compost application at the rate of 50 t ha^{-1}, and poultry manure application with 4 t ha^{-1} in combination with NPK improved yield and yield components and macro nutrient composition of corn. Moreover, because of the high sand content of study soil, the treatments do not lead to any soil pollution problem. However, they might lead to pollution of groundwater. Before applying of poultry manure to the soil, it is recommended to measure the salt concentration.

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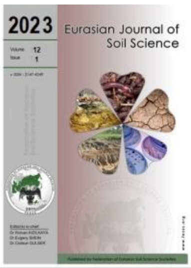

Characterization of arid soil quality: Physical and chemical parameters

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Abstract

Land degradation especially as a result of the rapid increase in demand and pressure in the population, have emerged as one of the most important problems. Degradation leads to the loss of biological and economic productivity due to the fact that the soil loses its functional properties, which are one of the most important elements of the terrestrial ecosystem. Combined with excessive biophysical and socio-economic damage in arid areas, land degradation causes irreversible consequences leading to desertification. Thus, land degradation is an environmental threat not only on a local or regional scale, but also on a continental or even global scale. The change in the state of soils as a result of anthropogenic impact and climatic changes determines the relevance of conducting a study of the soils of the Republic of Kalmykia. Endosalic Calcisols of sandy loam and sandy granulometric composition predominate in the structure of the soil cover of the southern part of the Caspian lowland, significant areas are occupied by sands. More than 70% of agricultural land is subject to wind erosion. Salt marshes are widely distributed.

Keywords: Caspian lowland, arid soil, organic carbon, soil acidity, heavy metals.

Introduction

The problem of soil degradation is one of the main manifestations of negative processes, which can be attributed to a global problem throughout the world. The area of eroded lands is increasing every year. The problem of desertification is the result of anthropogenic impact on natural resources and is a socio-ecological and economic problem, as it poses the biggest challenge to all mankind for its sustainable development (Dordzhiev et al., 2018).

Degraded territories occupy more than 41% of the area on the globe. The eroded lands in the Russian Federation is about 100 million hectares of agricultural land. The greatest distribution of degradation processes is observed on the territory of the Caspian lowland at the South of the European part of Russia, in such areas as the Republic of Kalmykia, Rostov, Astrakhan, Volgograd regions and the Republic of Dagestan. Degradation processes are manifested to a greater extent in arid regions, where there is significant climate change, such as drought, as well as technogenic pressure on nature due to man vigorous activity, irrational use of natural resources (Glazovskaya and Gorbunova, 2002; Novikova et al., 2022).

The active desertification processes are noted on the territory of the Caspian lowland due to the prolonged droughts, wind erosion, as well as inefficient use of water for irrigation, soil salinization, overgrazing, unjustified use of chemicals that cause soil and water pollution. All these processes lead to a decrease and deterioration of the soil layer, blowing out of the soil layer of dehumification and the formation of mobile sands (Dordzhiev et al., 2018).

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The Republic of Kalmykia is currently a zone of ecological disaster. The main reason for the appearance of anthropogenic phenomena on the territory is the irrational use of land, internal and external impacts on the soil layer, etc. In addition to the main natural factors in the formation of degradation processes, the territory of the region is affected by the facts of human economic activity, one of which is overgrazing, which leads to the irrational use of soil and plant resources, in combination with water and wind erosion, the destruction processes have an accelerated rate of development (Bakinova et al., 2019). The problem of desertification and land degradation in the Kalmykia is one of the most urgent, as it is associated with ongoing irreversible changes in the natural potential of territories and environmental degradation of living space (Bakinova et al., 2019). Desertification and land degradation in the Kalmykia have not only environmental, but also negative socio-economic consequences (Glazovskaya and Gorbunova, 2002).

The purpose of this study was to characterize the quality of arid soil of the Caspian lowland: the physical and chemical parameters, in order to assess changes in the soil cover.

Material and Methods

The territory of the Republic of Kalmykia is located in the southeast of the European part of Russia at the Caspian lowland. It occupies 76.1 thousand square meters (0.4% of the area of the Russian Federation). The climate of Kalmykia can be characterized as warm, dry, sharply continental with long hot summers and rather severe but unstable winters. The amount of precipitation varies from 180 to 495 mm per year (Tashninova, 2015).

The studied territories are the settlements of the Yashkul district, which located on the territory of the Republic of Kalmykia at the Caspian lowland, distinguished by very harsh natural and climatic conditions (Tashninova, 2015). The Yashkul district of the Republic of Kalmykia occupies 11,769 sq. km. The study area is completely located in the redistributions of the Caspian lowland. The south-west of the district is partly located on the eastern slopes of the Ergeninsky Upland.

In the settlements of the Yashkul district, monitoring sites have been laid in the center of the settlement or on the territory of a school, on the border and at a distance of 500 m from the borders of the settlement. In total, 18 medium soil samples were taken for the study, in the territory of 8 settlements (Figure 1). Soil sampling was carried out in 7 settlements of the Yashkul district: the village of Chilgir, the village of Ulan-Erge, the village of Elvg, the village of Ermeli, the village of Hogn, the village of Gashunsky, the village of Yashkul. Samples were taken from the surface layer of 0-20 cm. The physical and chemical state of the soils was studied.

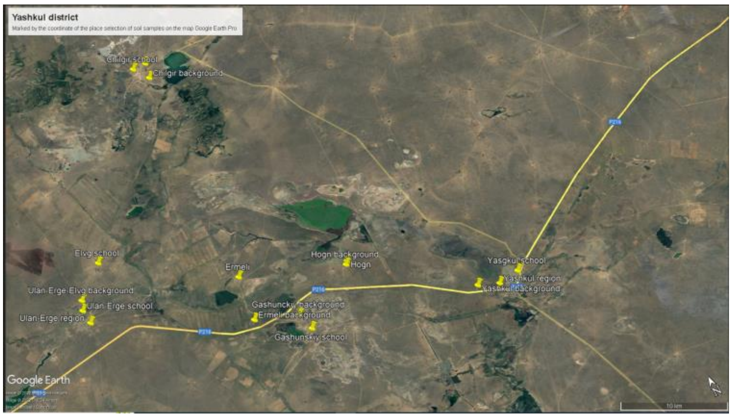


Figure 1. Location of soil monitoring sites on the territory of the Republic of Kalmykia at the Caspian lowland.

The soils of the region are represented by Endosalic Calcisolspre dominantly deflated soils. They differ from Haplic Kastanozems Chromic is a much smaller amount of humus. Depending on the nature of parent rocks, the mechanical composition of soils varies from light loamy to sandy. Significant areas are occupied by sands. More than 70% of agricultural land is subject to wind erosion. Solonetzes and solonchaks are widespread (Tashninova, 2015; Bakinova et al., 2019; Sangadzhieva et al., 2019; Lazareva et al., 2020).

The landscape of the Yashkul region is formed by sandy and sandy sea and delta-sea late Khvalyn plain: in the eastern part with traces of the ancient delta relief such as lagoons, ramparts, estuaries, bay-bars, in the south - dunes, blowout basins, occasionally with Burr hillocks. Relative height fluctuations from 0-5 to the north to (-20) m in the south. In addition, the plain is complicated by eolian processes. Covering deposits are slurry, sands, loams. Zonal vegetation cover was formed by *Artemisia absinthium*. There are camphor-sagebrush-free semi-shrub deserts in combination with psammophyte sagebrush free Siberian hummock and sagebrush-fescue-tyrsichkovy steppes, with sandy *Artemisia tridentata*, *Calligonum* communities on the sands and petrosimonium associations (Sangadzhieva et al., 2019).

Methods

The soil particle size distribution was performed according to ISO 13317–2:2001. The pH in 1:5 soil/water suspension was measured using a glass electrode according to ISO 10390:2005. The carbonates content was determined by volumetric method on a Scheibler apparatus according to ISO 10693:1995. Total organic carbon (Corg) content was determined by sulfochromic oxidation (ISO 14235:1998). The exchangeable cations Ca^{2+} and Mg^{2+} were determined using a hexamine cobalt trichloride solution (ISO 23470:2018). The chemical composition of soils was studied by X-ray fluorescence spectroscopy using "Spectroscan MAKC-GV" (Spectron, Russia).

Statistical analysis

To carry out statistical processing of the data of the research results, it was determined indicators, such as the concentration coefficient - K_k, the coefficient of the relative accumulation of trace elements in the soil - K_{cr}, and the background concentration coefficient - K_f. Elements with high Kk values are typomorphic and determine the geochemical setting. The calculation of indicators was carried out using the methodology of Glazovskaya (1999).

Statistical data processing was carried out using the Microsoft Excel software package.

Results

In all soil samples, the contents of organic carbon were determined (Table1). The content of organic carbon in the studied soils of the Yashkul region varied from 0.31% to 1.89%. The maximum values (1.89%) were recorded in the village of Ermeli, the minimum on the territory (0.31%) was in the village of Chilgir. According to the content of organic carbon in soils, it can be concluded that the soils are mostly low-humus.

Table 1. Content of organic carbon and pH in Endosalic Calcisols Sodic

Place of sampling	pH	Corg, %
Chilgir background	7.2 ±0.11	1.08 ±0.34
Chilgir	7.4 ±0.11	1.46 ±0.34
Chilgir school	7.6 ±0.11	0.31 ±0.35
Ulan-Erge	7.6 ±0.15	0.66 ±0.133
Ulan-Erge school	7.9 ±0.15	0.46 ±0.133
Elvg	7.9 ±0.1	0.92 ±0.174
Elvg school	7.9 ±0.1	1.35 ±0.215
Ermeli	7.6 ±0.1	0.79 ±0.55
Ermeli background	7.6 ±0.1	1.89 ±0.55
Hogn	8.0 ±0.5	1.14 ±0.23
Hogn background	7.0 ±0.5	0.69 ±0.23
Gashunsky school	8.0 ±03	1.35 ±0.03
Gashunsky background	7.4 ±0.3	1.29 ±0.03
Yashkul background	7.7 ±0.13	1.68 ±0.05
Yashkul	7.3 ±0.13	1.52 ±0.05
Yashkul school	7.7 ±0.13	1.52 ±0.05

The selected samples in the settlement of the village of Chilgir have content of organic carbon value of 0.31-1.46 gm/kg, the highest value was noted at the point taken at the edge, the lowest on the territory of the school, the data show that the school territory is less humus, it can be assumed that this is due from business activities. The results on the territory of Ulan-Erge have approximately equal values, and do not change significantly with distance. In the village of Elvg, the highest value is observed at the sampling point on the territory of the school 1.35 mg/kg, which is most likely due to the fact that on the territory of the school manure was applied, and humus was formed due to the large amount of greenery and trees.

The difference in the values of the humus content was most likely due to the fact that in the territory of the background value, the soils are covered with vegetation, and the center of the settlement, under the influence of the anthropogenic factor from the side of people, cars, has a minimum vegetation cover, respectively, the formation of plant residues was not formed.

On the territory of the village of Hogn, the highest value of humus was observed in the center of the settlement - 1.14 mg/kg, the background value was 0.69 mg/kg. The values of humus content in the territory of Gashunsky settlement were 13.5 mg/kg in the territory of the school, and 1.29 mg/kg in the territory of 500 m from the settlement. High rates of soil humus are due to a large amount of vegetation throughout the village, as well as the formation of organic fertilizer as a result of livestock breeding.

The content of humus in Yashkul settlement had the highest value at the sampling point of the background value was 1.69 mg/kg, and the content of humus at the points "edge" and "school" was equal to 1.52 mg/kg. The values were approximately equal, most likely, because the village of Yashkul is a populated settlement where the landscaping takes place.

In the semi-desert zone of Endosalic Calcisols Sodic, the accumulation of Mo, V, Ti, Sn was found in the upper horizons; with a non-contrasting distribution, cationogenic elements – Co, Ba, Ni, Mn, Cu were accumulated (Table 2). The accumulation of elements associated with soil salinization was noted, these were Co, Mo, and Mn, which accumulate in the salt crust and in the upper saline horizon (Sangadzhieva et al., 2019).

Table 2. Average content of heavy metals in the Endosalic Calcisols Sodic of the Caspian Lowland.

Place of sampling	V	Cr	co	Ni	Cu	Zn	As	Sr	Pb
Chilgir	72.56±3.0	133.0±9.8	11.97±0.9	52.71±4.3	33.85±1.84	79.01±11.36	7.24±1.14	168.35±3.78	25.78±2.73
Ulan-Erge	80.4±4.7	155.9±30.4	15.3±1.17	41.9±8.06	27.6±4.8	67.11±5.5	7.4±1.04	193.0±11.26	20.9±4.55
Elvg	96.25±2.0	116.1±5.85	14.0±2.0	62.5±3.18	41.7±0.39	108.3±1.4	5.4±0.93	166.8±3.75	36.04±1.48
Ermeli _	90.81±5.8	116.7±116.7	14.27±1.05	53.8±3.24	39.8±1.6	62.8±2.65	6.3±1.29	221.3±43.54	24.5±3.37
Hogn	85.4±10.8	108.4±3.37	13.8±0.28	59.2±0.62	39.5±1.37	76.1±1.98	5.5±0.6	172.9±6.02	27.25±3.2
Gashunsky	86.9±0.07	134.5±23.0	14.2±1.37	57.2±2.9	42.34±3.06	78.2±9.73	6.7±1.75	178.4±17.3	26.6±3.28
Yashkul	82.84±0.09	116.7±9.4	11.8±1.24	55.1±1.08	39.09±1.37	84.09±8.5	5.9±0.5	215.4±26.1	25.7±1.08
MPC	150.0	100.0	5.0	85.0	55.0	100.0	2.0	600	30.0
Hazard Class	I	I	I	I	I	II	II	III	II
Clark according to Vinogradov	100.0	200.0	8.0	58.0	14.7	83.0	1.7	-	16.0
In Endosalic Calcisols Sodic of the Caspian lowland	-	40.0	8.0	20.0	1.8	16.0	-	-	16.0
Background content in soils of the world	-	200.0	10.0	40.0	20.0	50.0	-	-	10.0

The obtained values of the heavy metals content in the soils showed that the content of V was in the range from 66.70 to 98.33 mg/kg (Table 2). The Cr content in the soils of the studied area showed that the content varies within 98-202 mg/kg. High values were found on the territory of the school in the village of Ulan-Erge - 201.49 mg/kg. This concentration significantly exceeds the background concentrations of Cr in the Endosalic Calcisols Sodic of the Caspian lowland, but did not exceed the background content in the soils of the world, as well as the Clarke values according to Vinogradov of this element.

The obtained values of the Co content showed that its maximum concentration was 16.12 mg/kg, taken on the territory of the school in the village of Elvg. The obtained values of the average concentration of Co in the territory of the studied sites significantly exceeded the given background regional values by 1.5-2 times (Table 2). The content of Ni in the analyzed soil samples was in the range of 44.34-65.73 mg/kg. In comparison with the background content the excess concentration was significant. The maximum value of the Ni was found in the soil sample taken between the village of Ulan-Erge and the village of Elvg exceeded background regional values by 2.5 times. The content of Cu in soil samples was in the range of 27.38-42.61 mg/kg. The highest value was found in a soil sample taken at the edge of the village of Yashkul. The background content was 1.8-2.5 mg/kg and the excess was 15-17 times. The content of Zn in the soils of the Yashkul region varies between 56-110 mg/kg (Table 2). The background content in relation to the indicators of the regional content of Zn in the soils of the Caspian lowland was 3-6 times higher. Compared to the Clark value according to Vinogradov, the excess was 1.2 times. And the background content of the world was exceeded by 2 times. The concentration of As in the analyzed soil samples was in the range of 49-27 mg/kg. The content of Sr in soils showed that the values of the concentration of the element varies from 161.16-266.41 mg/kg (Table 2). The highest value was found in a soil sample taken at the edge of the village of Yashkul. The average content of this element did not exceed MPC values. Determination of the Pb concentration in the soils showed that its content varies within 20.54-37.52 mg/kg. High values were found near the school in the village of Elvg. These values of the Pb content significantly exceeded the background values. The average value of the majority of the analyzed elements in the soil samples of the Yashkul district did not exceed or slightly exceeded the maximum permissible concentration (MPC), and the Clarke values according to Vinogradov. But the content of the analyzed elements significantly exceeded the regional Clarke.

To assess the distribution and accumulation of toxicants in soils the analysis of variance were carried (Table 3). In order to determine the nature of technogenic pollution, it was necessary to calculate the values of the concentration coefficients Kc (the ratio of the element content in the soil to the content in the lithosphere), the coefficient of the relative accumulation of trace elements in the soil Kcr (the ratio of the trace element content in the soil to the background level), the background concentration coefficient Kf (the ratio of the content of trace elements to the background) (Figure 2).

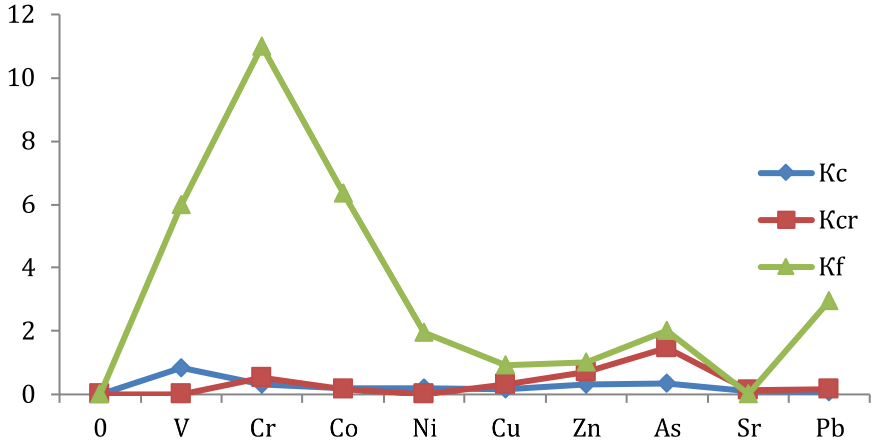


Figure. 2. Geochemical spectra of metals in the Endosalic Calcisols Sodic: Kc - to the regional clarke, Kcr - to the lithosphere clarke, Kf - to the background Clarke

Table 3. Analysis of variance of the results of the determination of metals.

Element	Kk	Kkr	Kkf	Shares of MPC
V	0.19	-	1.94	0.48
Cr	0.84	0.64	11.0	1.33
Co	0.42	0.40	0.95	2.30
Ni	0.30	0.65	one	0.62
Cu	0.36	1.0	2.94	0.62
Zn	0.37	0	1.25	0.79
As	0.07	0.04	one	4.26
Sr	0	0	2.48	-
Pb	0.18	0.19	6.36	1.61

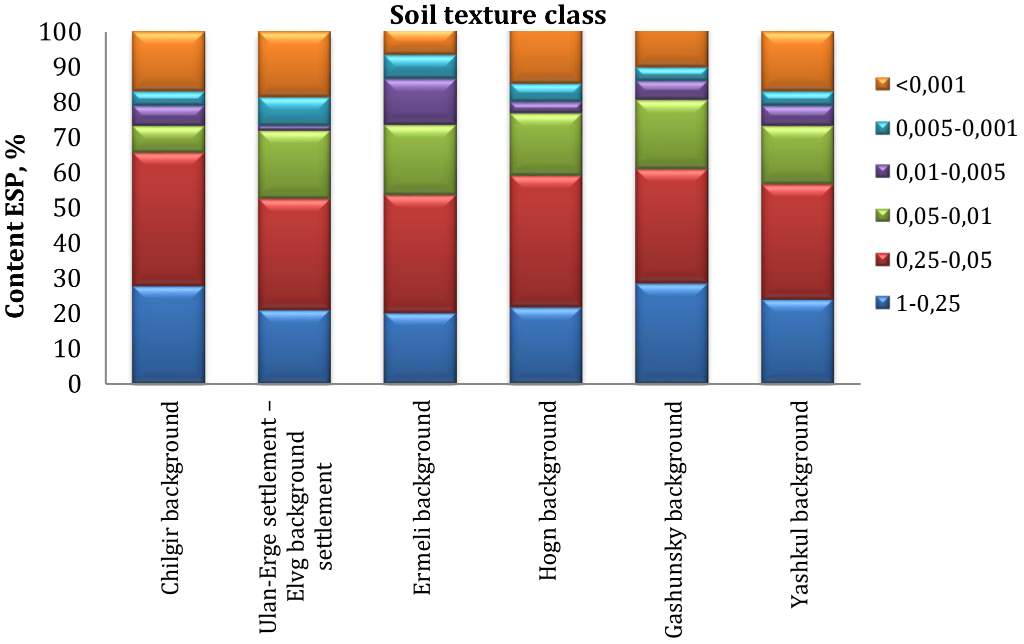
The data obtained for the determination of cations in the samples under study are presented in Table 4. The chemical composition of the soil is the main reflection of the elemental composition of all geospheres that take part in the formation of the soil (Lhissou et al., 2014). Allows you to determine the absorption capacity of the soil. With its help, the values of the provision of soil with nutrients were determined. The chemical composition of the soil showed that the soil need for fertilizer. The composition of the soil includes 15 main elements of the periodic system of Mendeleev, a greater number of elements had a low content or were quite rare. The Endosalic Calcisols Sodicare enriched in Si and Mg. It was very poor in Ca, P and K.

Table 4. Chemical composition of soils of the Caspian Lowland

Place of sampling	Na_2O (%)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	TiO_2 (%)	Fe_2O_3 (%)	MnO (mg/kg)
Chilgir background	1.22±0.12	1.74±0.13	11.86±0.31	67.67±1.54	0.15±0.02	2.41±0.03	1.53±0.53	0.66±0.02	3.54±0.31	752.76±38.5
Chilgir	0.80±0.12	1.85±0.13	12.29±0.31	62.35±1.54	0.22±0.02	2.49±0.03	3.04±0.53	0.64±0.02	4.07±0.31	797.28±38.5
Chilgir school	0.95±0.12	2.17±0.13	12.94±0.31	64.97±1.54	0.14±0.02	2.40±0.03	1.37±0.53	0.72±0.02	4.60±0.31	883.76±38.5
Ulan-Erge	1.15±0.15	1.69±0.10	11.04±0.71	64.50±1.21	0.14±0.02	2.10±0.29	4.31±121	0.69±0.02	3.27±0.64	574.07±164.6
Ulan-Erge school	1.18±0.15	2.04±0.10	11.67±0.71	60.45±1.21	0.17±0.02	2.15±0.29	5.19±1.21	0.65±0.02	3.60±0.64	579.68±164.6
Elvg background	0.71±0.18	1.84±0.07	13.41±0.57	63.41±0.99	0.21±0.013	2.99±0.225	1.19±0.65	0.72±0.28	5.32±0.51	1070.76±41.6
Elvg school	1.14±0.22	1.76±0.04	12.54±0.435	64.97±0.78	0.22±0.005	2.67±0.16	1.34±0.07	0.79±0.04	4.56±0.38	1107.97±18.6
Ermeli	1.17±0.02	1.58±0.42	11.64±0.29	70.27±6.32	0.09±0.02	2.33±0.07	1.11±2.83	0.79±0.04	3.76±0.27	864.79±84.6
Ermeli background	1.14±0.02	2.41±0.415	12.22±0.29	57.62±6.32	0.14±0.02	2.19±0.07	6.76±2.83	0.72±0.04	4.30±0.27	695.46±84.6
Hogn	0.87±0.06	2.21±0.17	13.13±0.07	61.49±1.49	0.19±0.02	2.64±0.03	2.05±0.37	0.68±0.72	4.63±0.01	760.79±69.6
Hogn background	0.99±0.06	1.87±0.17	13.27±0.07	64.47±1.49	0.16±0.02	2.70±0.03	1.30±0.37	0.75±0.72	4.65±0.01	900.11±69.6
Gashunsky school	1.14±0.12	1.99±0.015	12.48±0.11	63.17±1.0	0.20±0.035	2.62±0.23	2.86±0.62	0.78±0.01	4.67±0.17	930.65±70.2
Gashunsky background	0.90±0.12	2.02±0.015	12.70±0.11	61.17±1.0	0.13±0.035	2.17±0.23	1.63±0.62	0.80±0.01	4.33±0.17	790.34±70.2
Yashkul background	1.24±0.07	2.29±0.295	12.13±0.21	61.96±1.83	0.17±0.06	2.49±0.11	3.22±1.69	0.69±0.01	4.18±0.13	740.89±78.8
Yashkul	0.86±0.07	2.51±0.295	12.21±0.21	57.69±1.83	0.14±0.06	2.28±0.11	6.61±1.69	0.70±0.01	4.34±0.13	720.64±78.8
Yashkul school	1.01±0.07	1.92±0.3	11.80±0.21	61.34±1.83	0.25±0.06	2.50±0.11	3.23±1.69	0.68±0.01	4.08±0.13	878.15±78.8

The texture of soils is the main physical parameter of soils, which shows the level of fertility. The granulometric composition shows the development of physical properties of the soil, such as porosity, moisture capacity, water permeability, etc., shows the ratio of the content of macro- and microelements in soils and reflects the absorption capacity (Shein, 2009).

The soils are represented mainly by zonal Haplic Kastanozems Chromic and Endosalic Calcisols Sodic, their complexes with solonetzes and solonetzes. According to the results of the granulometric composition, it follows that the soils of the study area were characterized as medium loamy with a predominance of the sandy fraction (Figure 3).



Desertification processes are most intensive on soils of light granulometric composition. The content of soil particles < 0.001 mm in the 0-20 cm layer was 5.4-18.4, the lowest values were observed in the territory of the village of Yashkul, the village of Ermel, the village of Chilgir. The content of soil particles < 0.01 mm ranges from 20.6-29.8, the lowest values were noted in the village of Chilgir, the village of Yashkul, on the territories of schools (Figure 4).

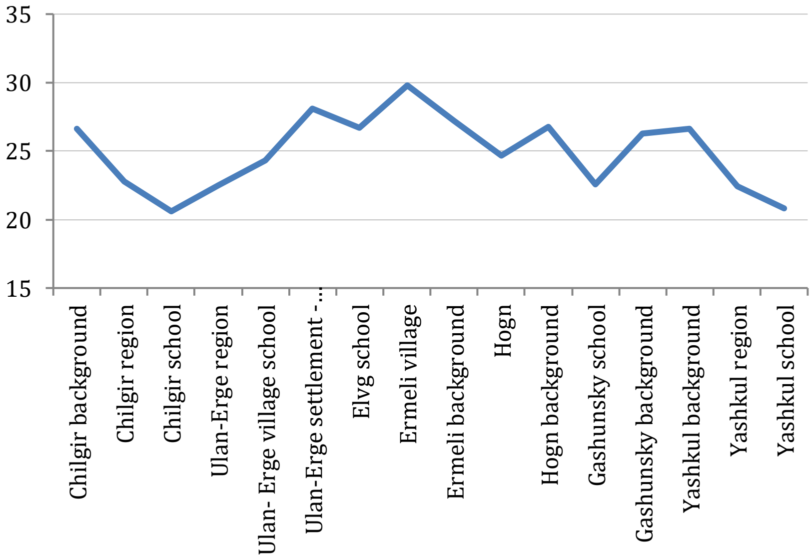


Figure 4. Distribution of soil particles >0.01 mm in Endosalic Calcisols Sodic.

Discussion

Morphological features of Endosalic Calcisols were described as soils characterized by low power of the humus layer and weak differentiation of the profile. The destruction of the organic component under the influence of aerobic processes is characteristic of soils of this type (Tashninova, 2015).

The thickness of the humus layer in Endosalic Calcisols Sodic was 30-40 cm, the humus content at a depth of 0.3-1.12% was insignificant, the reaction of the soil solution was neutral at the top (pH 6,7-8,2), an increase in alkalinity occured at the bottom (Bakinova et al., 2019).

On the territory of Kalmykia, under the conditions of insufficiency of humid processes, arid climate, high content of salts in soils, and low content of humus, the migratory ability of microelements significantly increases in soils with a light granulometric composition, which have an increased leaching capacity. In the steppe zone in the desert steppe subzone, to which the study area belongs, the mobility of microelements decreases due to the alkalinity of soils (Buluktaev, 2018; Sangadzhieva et al., 2019; Tumanyan et al., 2019).

According to the data obtained, it can be observed that when compared with Clark according to Vinogradov, all elements $_{Kc}$ < 1. Soils did not pose a threat for all detected metals. The series formed in soils:

Co >Ni >As >Zn >V >Sr >Cu >Pb >Cr.

For comparison with the obtained values of the accumulation of concentrations of heavy metals in the territory of the Yashkul district, it is possible to build series of metals accumulation for each settlement.

Chilgir: As>Co>Pb>Cu>Ni>V>Zn>Cr>Sr
Ulan - Erge: As>Co>Pb>Cu>Ni>Zn>V>Cr>Sr
Elvg: As>Co >Pb>Cu>Ni>V>Zn>Cr>Sr
Ermeli: As>Co >Pb>C u>Ni>Zn>V>Cr>Sr
Hogn: As>Co >Pb>Cu>Ni>Zn>V>Cr>Sr
Gashunsky: As>Co >Pb>Cu>Ni>Zn>V>Cr>Sr
Yashkul: As>Co >Pb>Cu>Ni>Zn>V>Cr>Sr

To identify the features of the distribution of heavy metals in the studied soils of the territories, the method of geochemical spectra was applied, the spectra were built according to the clarks of the concentration or dispersion of elements. The coefficient of regional concentration - Kcr is the ratio of the average content of the element in the soil to its background in the territory of the Caspian lowland (Figure 2).

Based on the analyzes of the metals accumulation, samples of the studied soils, their ecological and geochemical specialization was revealed. In comparison with the values of metals content in Endosalic Calcisols Sodic of the Caspian lowland, the soils of the study area showed the accumulation of all analyzed elements. As a result of studies of the chemical composition of the soils at the studied territories, it was found that the soils of the region have insignificant accumulations of the studied elements.

Conclusion

According to the results based on the determination of the chemical composition of the soils on the territory of the Yashkul district, several conclusions can be made:

1. Studies on the metals content in the soils of the studied area showed that the average values of most of the analyzed elements did not exceed or slightly exceed the maximum permissible concentrations. But the content of the analyzed elements significantly exceeded the regional clarke.
2. The content of organic carbon in soil samples varieв from 0.31% to 1.89%. The maximum values (1.89%) were recorded in the village of Ermeli, the minimum was on the territory (0.31%) of the village of Chilgir. The soils were mostly low-humus.
3. The reaction of the soil solution is neutral or slightly alkaline.
4. According to the results of the analysis of the soil texture, the studied soils are characterized as medium loamy with a predominance of the sandy fraction.

According to the data obtained, it can be concluded that the territory of the Yashkul district was subject to changes in the soil cover under the influence of anthropogenic factors, as well as natural and climatic factors, which leads to degradation of territories and the movement of sands.

Acknowledgements

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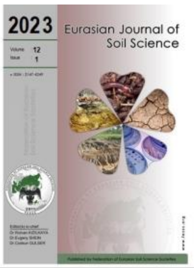

Soil properties and growth of yellow bell pepper (*Capsicum annum*) as influenced by compost and arbuscular mycorrhizal fungi

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Abstract

Compost is an inexpensive agricultural waste which improves soil health and quality. The experiment was carried out to assess the influence of compost and mycorrhizal inoculation (*Glomus mosseae)* on soil properties and growth of yellow bell pepper in pots under screen house conditions, in a completely randomized design with three replicates. The treatments included mycorrhizal inoculation only (C0M1), compost at 20 t ha^{-1} only (C1M0), compost at 30 t ha^{-1} only (C2M0), compost and mycorrhizal inoculation at 20 t ha^{-1} (C1M1), compost and mycorrhizal inoculation at 30 t ha^{-1} (C2M1) and control (no amendment / uninoculated). Compost and mycorrhizal inoculation (C1M1 and C2M1) significantly improved soil N, P and K compared to control. Inoculation with mycorrhizal only (C0M1) increased uptake of N, P, K, Ca and Mg compared to uninoculated. Co-utilization of compost and mycorrhizal inoculation significantly increased root and shoot dry biomass compared to uninoculated. The highest fruit yield was obtained at C2M1 followed by C1M1 in comparison to compost application only. Treatment C2M1 recorded the highest prevalence of percent root colonization. This suggests that compost and *Glomus mossea* could be considered to have a sustainable potential for better growth and yield performance in the production of yellow bell pepper in an Alfisol.

Keywords: Arbuscular mycorrhizal fungi, compost, nutrient uptake, soil fertility, soil nutrient.

Introduction

Many agricultural lands require an intervention strategy to improve the nutrients contents of the soil. The organically managed soil systems in the tropics are increasingly utilized to combat constraint to food security (Chukwuka and Omotayo, 2009). Major factors that constrain agricultural soil fertility are caused by excessive erosion, nutrient run-off, loss of organic matter and low soil biodiversity (Santos et al., 2011). Compost, an effective organic fertilizer produced from organic waste biomasses (Patchaye et al., 2018). The use of organic biomass as soil conditioner is now rapidly gaining importance in tropical agriculture as it promotes soil physical, chemical and biological properties (Zong et al., 2010; Gautam and Pathak, 2014). Furthermore, evidence suggest that application of compost to soil increase soil organic matter, promotes soil fertility and activities of soil microbial communities (González et al., 2010; Carlson et al., 2015; Cozzolino et al., 2016). The application of compost resulted to increased soil available macro and micro nutrients that stimulates microorganism development in soils (Biala, 2000); moreover, compost significantly increases crop growth and activities of soil microorganisms (Gosling et al., 2006; Weber et al., 2007). Compost is a potential habitat for arbuscular mycorrhizal fungi (AMF) functionality (Warnock et al., 2010). Arbuscular mycorrhizal fungus is important in sustainable agriculture since mycorrhizal association hastens nutrient acquisition for crop growth and development (Hu et al., 2009; Smith et al., 2015). According to Hodge and Fitter (2010), the co-

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amendment of compost and mycorrhizal inoculation increased crop growth better than either sole amendment due to arbuscular mycorrhizal fungi ability to exploits nutrients released by mineralization of organic matter. One of the benefits derived by host of arbuscular mycorrhizal fungi is that it enhances the absorption of soil mineral nutrients, which includes the major and micro nutrients (Linderman, 1992; Perner et al., 2007). The availability of these nutrients is usually affected by soil property, climate and crop type (Cely et al., 2016). Phosphorus has been described in literature as poorly accessible plant nutrient because of its immobility in soils (Smith and Read, 2008; Neumann and George, 2010). Evidence by research has confirmed AM fungi provides multifunctional benefits to soil by improving aggregate stability, creating more resistance to water stress and diseases which mostly depends on origin and species compatibility (Jung et al., 2012; Verbruggen et al., 2013). Horticultural crop such as yellow bell pepper is one of the major components of traditional food in Nigeria. It is known to be rich in vitamins and minerals (Malik et al., 2011) and play significant roles in disease prevention including diabetes, fever, heart and cancerous diseases (Serpeloni et al., 2015; Shahidi and Ambigaipalan, 2015). They are commercially produced due to its high demand and value which is mostly nutritive and medicinal purpose (Tanwar et al., 2021). However, yield and fruit quality are affected by a number of environmental factors such as type of soil, chemical fertilizer, pests and diseases (López et al., 2014). There is need to meet rising demands by adopting sustainable practices to assist in improving the soil, increasing crop growth and enhance mineral nutrient uptake. Several authors reported positive outcome of utilizing arbuscular mycorrhizal fungi on horticultural crops most especially *Glomus species* (Tanwar et al., 2011; Krüger et al., 2012). *Glomus mosseae* is known to provide specific benefits with horticultural crops by improving fruit yield and quality (Franco et al., 2013). It can facilitate uptake of mineral nutrients, promote growth and develop symbiotic association in rhizospheric region of pepper plants (Nadeem et al., 2014; Rouphael et al., 2015; Smith et al., 2015). Therefore, the objective of this study is to evaluate the effect of compost and *Glomus mosseae* inoculation on improving soil fertility, growth and yield of yellow bell pepper.

Material and Methods

Experimental site and design

The experiment was performed at the screen house of the Department of Agronomy University of Ibadan Nigeria (7°24'N; 3°48'E) between June and August, 2020. Soil samples were collected at 0-20 cm depth at Teaching and Research farm and transported in plastic bags to the screen house. A completely randomized design with three replicates involving yellow bell pepper (*Capsicum annum* L) at two seedlings per pot, and two treatment factors: compost and mycorrhizal inoculation. Three levels of compost applied in this study: 0, 20 and 30 t ha^{-1} (equivalent to 0, 50 and 75 g compost per pot); two rates of mycorrhizal inoculation at 0 and 20 gram per pot and each treatment with 5 kg soil per pot.

Soil and plant analysis

Soil pH in water measured using pH meter. The particle size analysis was carried out by Gee and Or (2002) indicating loamy sand texture and classified as an Alfisol according to US soil taxonomy, total nitrogen by Kjeldahl method (Bremmer, 1996) and organic carbon was determined by Walkley–Black method (Nelson and Sommers, 1996). Available phosphorus was by Bray extraction method (Frank et al., 1998). The Exchangeable bases K^+, Ca^{2+} and Mg^{2+} was extracted using 1N ammonium acetate, where K^+ was determined by flame photometer and Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrophotometer (Okalebo et al., 2002). Plant samples were oven-dried (70^{0}C) and milled. Then, digested milled samples were used to determine N content by Kjeldahl method (Bremmer, 1996). The samples were dry ashed in a furnace (500^{0}C for 6 h) and extracted using nitric-perchloric-sulfuric acid mixture which was used to detect phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) according to Tel and Hagarty (1984). Afterwards, P was finally determined by vanadomolybdate colorimetry method, K by flame photometer while a method of titration (EDTA) was used to determine Ca and Mg (AOAC, 2005).

Plant, compost and mycorrhizal treatment

The pepper seedlings used in this study was yellow bell pepper (*Capsicum annum* L.) collected from Institute of Agriculture and Research Training Ibadan Nigeria. Animal waste compost was collected from Organic farm of the Federal University of Agriculture Abeokuta Nigeria. Arbuscular mycorrhizal fungi (*Glomus mosseae*) inoculum was originally and commercially obtained from Biocult Pty Limited, South Africa and collected from soil microbiology laboratory of Department of Agronomy, University of Ibadan Nigeria. It was multiplied in pot cultures using maize as host plant. The inoculum was applied to the third central part of the soil a day before transplanting yellow bell pepper seedlings (Ubah et al., 2012). Percent root colonization was done by observing stained roots under a dissected microscope (Giovannetti and Mosse, 1980).

Table 1. Soil physical and chemical characteristics and nutrient composition of compost

Parameters	Units	Soil		Units	Compost
pH(H_2O)		7.40	pH		8.03
TN	g kg^{-1}	0.42	TN	%	0.86
AP	mg kg^{-1}	7.23	AP	%	1.46
OC	g kg^{-1}	6.20	OC	%	20.70
K^+	cmol kg^{-1}	2.00	K	%	1.22
Ca^{2+}	cmol kg^{-1}	7.80	Ca	%	0.32
Mg^{2+}	cmol kg^{-1}	2.80	Mg	%	0.54
Particle Size Distribution					
Sand	%	73.80			
Silt	%	26.10			
Clay	%	2.00			
Textural Class		Loamy Sand			

TN = Total nitrogen, AP =Available phosphorus, OC=Organic carbon

Statistical analysis

The results of this experiment were obtained by one-way ANOVA using SPSS v 19.0. Differences were separated by Duncan Multiple Range Test (DMRT) at significance level of 0.05. All data presented are means of three replicates.

Results

Effect of compost and AMF on nutrient concentration

The effect of compost with or without AMF inoculation on the improvement of soil nutrients is shown in Table 2. The AMF inoculation only (C0M1) led to 29.1 % increase in total nitrogen (TN) concentration compare to control. Compost and AMF inoculation (C1M1) at 20 t ha^{-1} significantly increase (3.49 %) compared to C1M0 (compost application only) and control. Similarly, compost and AMF inoculation at 30 t ha^{-1} (C2M1) was higher by 3.92 % compare to compost application only (C2M0) and significantly higher than control (C0M0). Soil Ca content increased with or without AMF inoculation. Treatment with AMF inoculation only (C0M1) significantly increase compare to control. Both levels of compost and AMF inoculation (C1M1 and C2M1) were higher by 4.28 % and 3.57 % when compared to C1M0 and C2M0 respectively. Mg concentration showed AMF inoculation only (C0M1) increase by 6.95 % compare to control. C1M1 treatment at 20 t ha^{-1} was higher by 4.83 % when compared to compost application only (C1M0). Compost and AMF inoculation (C2M1) significantly increase compare to C2M0 at 30 t ha^{-1} and control. Application of compost with or without AMF inoculation influenced changes in K concentration. C0M1 increased by 7.63 % compare to control. Treatment C1M1 at 20 t ha^{-1} led to significant increase compare to compost application only (C1M0). The application of compost in combination with AMF inoculation (C2M1) showed no significant difference compare to C2M0. AMF inoculation only (C0M1) showed no significant effect compare to control in soil organic carbon (Figure 1). Compost and AMF inoculation at 20 t ha^{-1} was significantly higher by 5.23 % compared to the application of compost only (C1M0). Similarly, C2M1 significantly increase compare to compost application only and control. Available P showed significant differences (Figure 2). AMF inoculation only (C0M1) was higher by 28.67 % compared to control. Compost and AMF inoculation at 20 t ha^{-1} significantly increase compare to C1M0 and control. Similarly, C2M1 treatment at 30 t ha^{-1} significantly increase compare C2M0 and control.

Table 2. Nutrient concentration in soil as affected by compost and AMF inoculation

	TN (g.kg^{-1})	Ca (cmol.kg^{-1})	Mg (cmol.kg^{-1})	K (cmol.kg^{-1})
C0M0	0.95±0.06d	1.13±0.01d	1.07±0.01d	1.09±0.01e
C0M1	1.34±0.04c	1.25±0.02c	1.15±0.01d	1.18±0.02d
C1M0	1.38±0.02bc	1.34±0.02c	1.38±0.02c	1.24±0.02c
C1M1	1.43±0.01abc	1.40±0.03b	1.45±0.03c	1.31±0.01b
C2M0	1.47±0.02ab	1.62±0.03a	1.62±0.04b	1.38±0.01a
C2M1	1.53±0.01a	1.68±0.02a	1.94±0.03a	1.40±0.02a

Mean ± SE of three replicates are shown; different letters on numerical values indicate significant differences (▯ < 0.05) along the columns. C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20tha^{-1} only; C2M0=compost at 30tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30tha^{-1}.

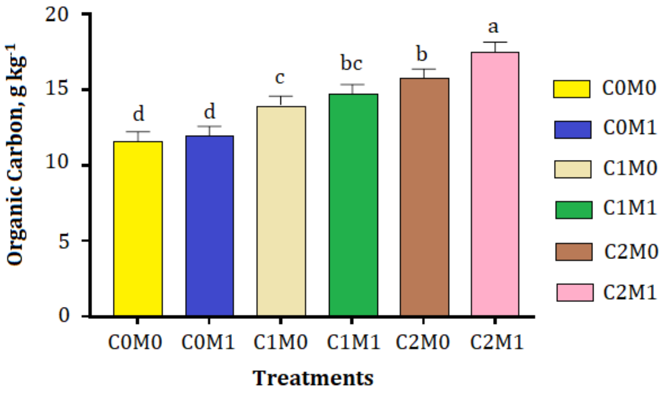

Figure 1. Organic carbon as affected by compost and AMF inoculation. Bars represent the mean ± SE of three replicates (⍰ < 0.05). C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20 tha-1 only; C2M0=compost at 30 tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20 tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30 tha^{-1}.

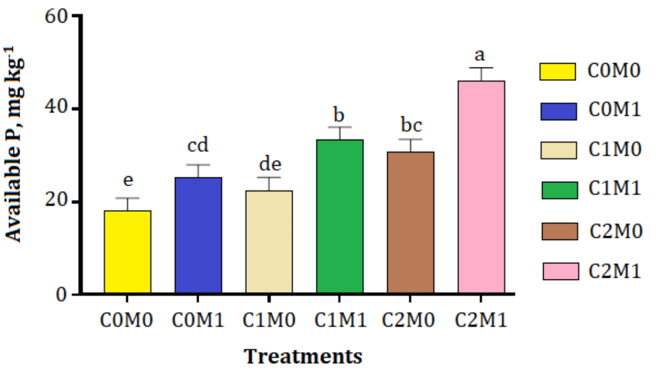

Figure 2. Available P as affected by compost and AMF inoculation. Bars represent the mean ± SE of three replicates (⍰ < 0.05). C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20 tha^{-1} only; C2M0=compost at 30tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20 tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30 tha^{-1}.

Effect of compost and AMF on nutrient uptake

Table 3 presents trends of compost application with or without AMF inoculation in uptake of nutrients. AMF inoculation only (C0M1) significantly increased N uptake compared to control. Compost and AMF inoculation (C1M1) at 20 t ha^{-1} significantly increase compare to compost application only (C1M0) and control. Treatment C2M1 and C2M0 (30 t ha^{-1}) showed no significant difference but both significantly higher than control (C0M0) for N uptake. Treatment application significantly differs in P uptake as shown in Table 3. AMF inoculation (C0M1) significantly increase compared to control. The application of compost and AMF inoculation at 20 t ha^{-1} significantly increase compared to C1M0. Similarly, C2M1 was significantly higher compared to compost application only at 30 t ha^{-1}. Ca uptake showed AMF inoculation only (C0M1) significantly increase compare to control. Treatment C1M1 was higher by 11.1 % compare to compost application only (C1M0). However, C2M1 at 30 t ha^{-1} significantly increase compare to compost application only (C2M0) and control. Mg uptake indicated compost application with or without AMF inoculation at both levels was significantly higher than control except AMF inoculation only (C0M1). The treatment C1M1 and C2M1 were significantly higher by 14.8 % and 7.46 % compared to C1M0 and C2M0 respectively. K uptake showed AMF inoculation only (C0M1) was 13.3 % higher compared to control. C1M1 was significantly higher compare to compost application only at 20 t ha^{-1} (C1M0). Compost in combination with AMF inoculation at 30 t ha^{-1} was higher by 5.8 % compare to C2M0.

Table 3. Nutrient uptake as affected by compost and AMF inoculation

	N (gkg^{-1})	P (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	K (mg kg^{-1})
C0M0	0.10±0.01c	1.11±0.01f	0.11±0.01e	0.12±0.01d	0.26±0.02d
C0M1	0.13±0.01bc	1.22±0.01e	0.20±0.02d	0.18±0.01d	0.30±0.01d
C1M0	0.17±0.01b	1.36±0.02d	0.24±0.01cd	0.46±0.03c	0.38±0.02c
C1M1	0.25±0.02a	1.56±0.02c	0.27±0.01c	0.54±0.04b	0.46±0.02b
C2M0	0.26±0.01a	1.66±0.02b	0.35±0.02b	0.62±0.02a	0.48±0.02ab
C2M1	0.27±0.01a	1.72±0.12a	0.47±0.03a	0.67±0.02a	0.51±0.01a

Mean ± SE of three replicates are shown; different letters on numerical values indicate significant differences (⍰ < 0.05) along the columns. C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20tha^{-1} only; C2M0=compost at 30tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30tha^{-1}.

Effect of compost and AMF on vegetative growth and percent root colonization

As shown in Table 4, the plant height basically increased after soil amendment. AMF inoculation (C0M1) significantly increase compare to control. Application of compost at 20 and 30 t ha^{-1} increase by 7.65 % and 7.83 % compared to compost and AMF inoculation respectively. Treatment with AMF inoculation showed no significant difference compare to control in stem diameter. The application of compost in combination with AMF inoculation (C1M1) was higher by 18.03 % compare to compost application only. Similarly, compost and AMF inoculation at 30 t ha^{-1} increase by 13 % compared to C2M0. Root dry biomass for AMF inoculation (C0M1) was significantly higher compared to control. Compost and AMF inoculation at 20 and 30 t ha^{-1} increased by 5.69 % and 6.08 % compare to compost application only. Shoot dry biomass revealed significant differences of treatment application. Inoculation with AMF only (C0M1) was significantly higher compared to control. Compost in combination with AMF inoculation at 20 and 30 t ha^{-1} significantly increase compare to C1M0 and C2M0 respectively. Significant increases in fruit yield were recorded with compost and AMF inoculation in comparison to compost only. Compost and AMF inoculation (C2M1) at 30 t ha^{-1} significantly increased (8.17%) compared to compost application only (C2M0). Similarly, compost and AMF inoculation (C1M1) at 20 t ha^{-1} was significantly higher compared to compost application only (C1M0). Inoculation with AMF only (C0M1) significantly increased compared to control. Percentage root colonization is presented in Figure 3. AMF inoculation (C0M1) significantly increase compared to control. Treatment C1M1 at 20 t ha^{-1} significantly increase compared to compost application only and control. Similarly, compost and AMF inoculation (C2M1) significantly increase compared to compost application only (C2M0).

Table 4. Vegetative growth of pepper plant as affected by compost and AMF inoculation

	Plant Height (cm)	Stem Diameter (cm)	Root Dry Biomass (g/pot)	Shoot Dry Biomass (g/pot)	Fruit Yield (g/pot)
C0M0	12.83±0.57d	0.46±0.02b	0.67±0.03e	1.07±0.02f	0.71±0.31e
C0M1	16.03±0.42c	0.47±0.02b	1.04±0.02d	1.31±0.03e	2.37±0.05d
C1M0	17.90±0.12bc	0.50±0.03b	1.16±0.01c	2.14±0.02d	4.01±0.06c
C1M1	16.53±0.31bc	0.61±0.03ab	1.23±0.02c	2.23±0.01c	5.71±0.02b
C2M0	20.43±0.56a	0.60±0.01ab	1.39±0.02b	2.31±0.02b	5.84±0.19b
C2M1	18.83±0.24ab	0.69±0.01a	1.48±0.04a	2.40±0.01a	6.36±0.04a

Mean ± SE of three replicates are shown; different letters on numerical values indicate significant differences (⍰ < 0.05) along the columns. C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20tha^{-1} only; C2M0=compost at 30tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30tha^{-1}.

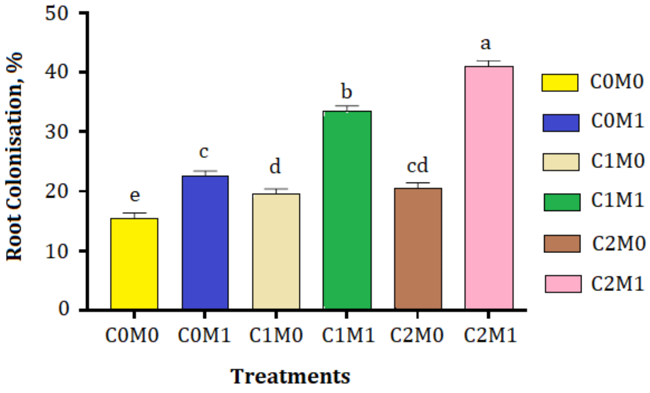

Figure 3. Percent root colonisaton as affected by compost and AMF inoculation. Bars represent the mean ± SE of three replicates (⍰ < 0.05). C0M0=control, C0M1= mycorrhizal inoculation at 20g only; C1M0= compost at 20 tha^{-1} only; C2M0=compost at 30 tha^{-1}only; C1M1=compost and mycorrhizal inoculation at 20 tha^{-1}; C2M1=compost and mycorrhizal inoculation at 30 tha^{-1}.

Discussion

We found evidence that in this study compost and AMF inoculation increase soil total N concentration. This result corresponds with that of Xu et al. (2015) who reported that AMF can access nitrogen from organic sources and also mineralization of compost in the soil help increase nitrogen content as declared by Aylaj et al. (2019). Astiko et al. (2013) argued that organic amendments with AMF inoculation increase soil N, P, K and organic carbon. It is important to note that AMF inoculation and organic amendment such as compost, manure, plant residue positively impact soil fertility status and biological activities (Warnock et al., 2007). The available P concentration in our study increased with compost and AMF inoculation compared to uninoculated. Ortas et al. (2012) reported that inoculation with mycorrhizal fungi increased phosphorus concentration compared to uninoculated plants which might be due to production of phosphatase enzyme. Also, Fischer and Glaser (2012) stated that organic additives contributed to increased concentration of phosphorus as a result of various nutrient releases such as nitrogen, phosphorus and potassium from compost application. In our study, the application of compost and AMF inoculation increased K concentration in the soil. This trend did not differ from Astiko et al. (2013) who reported organic amendment with AMF inoculation increased the concentration of K in the soil. In our study, compost and AMF inoculation significantly increase concentration of soil carbon. Quilliam et al. (2010) and Olsson et al. (2014) discovered that inoculation with symbiotic fungi aided nutrient exchange which promoted increase in soil carbon content. More so, incorporation of organic amendment will help improve the functions of AM fungi (Warnock et al., 2010) and increase soil N, P and K content as discussed by Demir and Gülser (2015). One of the most positive effects of mycorrhizal colonization is the increase in nutrient uptake. In this study, treatments showed significant increases in the nutrient uptake. The application of compost and AMF inoculation showed a positive response in N uptake. Earlier studies suggested that introduction of AM fungi enhanced the uptake of nitrogen (Hodge and Fitter, 2010; Whiteside et al., 2012). Mycorrhizal inoculated plants in combination with compost significantly influenced uptake of Ca, Mg and K. This conforms to Akande et al. (2018) who reported that AM fungi in combination with organic amendment increased Ca, Mg and K uptake. P uptake was promoted with compost and AMF inoculation in this study which was possibly due to phosphatase activity from external hyphal of AMF in rhizosphere (Widiastuti et al., 2003). It is ascertained that increased P uptake caused nutrients balance in plant and therefore promote uptake of other available soil nutrients (Boonlue et al., 2012). Furthermore, several mechanisms are responsible for increased P uptake, including soil exploration, absorption and release of phosphorus through fungal hyphae (Nazeri et al., 2014). Ortas (2012) proved that inoculation with arbuscular mycorrhizal fungi proved effective in soils with low phosphorus concentration than with higher content in a field research. In addition, compost in combination with AMF inoculation increased K uptake than uninoculated with compost. Perner et al. (2007) in earlier works concluded that arbuscular mycorrhizal fungi enhanced phosphorus and potassium uptake in pelargonium plant. The result of this study showed compost and AMF significantly contributed to increase in yellow bell pepper growth and yield compared to uninoculated. This affirms with Tanwar and Aggarwal (2013) who stated that inoculation with AMF especially *Glomus mosseae* promotes growth of red bell pepper due to its compatibility and ability to absorb nutrients from the soil. Also, Aminifard et al. (2013) in a research reported that *Capsicum species* exhibited rapid growth after incorporation of compost which might be related to the decomposition of compost materials and nitrogen mineralization. Furthermore, other authors reported that organic amendment and AMF relatively increased vegetative growth of tomato (Maaitah et al., 2014), red bell pepper (Tanwar et al., 2013b), green bell pepper (Tanwar et al., 2013a), Lentil (Hanif et al., 2013) and improved varieties of *Capsicum species* (Olawuyi et al., 2014). More so, improvement in plant growth might be attributed to supply of sufficient nutrients to soil and mutual connection of AMF and function in root zones as reported by Akyol et al. (2019). Another trending reason as stated by Tanwar et al. (2011) and Kim et al. (2010) is the ability of AMF to acquire and translocate nutrients via mycelia throughout the roots. In our study compost and AMF inoculation increased shoot and root dry biomass compared to uninoculated. This connotes the study of Olawuyi et al. (2014) who reported that organic amendment and AMF inoculation positively influenced shoot and root biomass of pepper plants in a field experiment. Çekic et al. (2012) stated that inoculation with *Glomus mosseae* significantly influenced shoot and root biomass yield of *Capsicum annuum* due to enhanced nutrient acquisition. An increase in biomass might be achieved through improved plant growth which suggests improved fresh shoot and root development (Tanwar et al., 2012). In addition, compost and AMF improved vegetative growth and yield of tomato and pepper plant as a result of symbiotic association between plant root and advanced uptake of mineral nutrients as investigated by Fawole et al. (2016) and Oni (2015). As documented in this study, AMF inoculated plants significantly increased root colonization compared to uninoculated. This relates to findings of other studies that AMF root colonization increased as a result of acquisition of phosphorus by the mycelia network of host root plant in the soil (Tanwar et al., 2014; Kim et al., 2017). Also, conforms to a report that increase in percent root colonization is as a result of increase in soil nitrogen content (Hodge and Fitter, 2010; Smith and Smith, 2011). Contrarily, a non-effective colonization has been attributed to increased level of phosphorus in the soil as stated by Prasad et al. (2012) and Naghashzadeh et al. (2013). The extent of development and colonization of fungi to roots is dependent of host plant, origin and strain of mycorrhiza as discussed by Mau et al. (2014) and Verbruggen et al. (2013). Yield is considered an important factor in production of horticultural crops. In this study, compost and AMF positively contributed to yield of yellow bell pepper of inoculated than uninoculated. This is relevant to findings of Copetta et al. (2011) who reported that green compost and AMF inoculation assisted in improving yield of tomato plants due to increased level of colonization and nutrients accumulation. AyanfeOluwa (2019) and Hossain et al. (2017) affirmed that utilization of compost and mycorrhizal inoculation enhanced growth and yield of horticultural crops by mutual association of AMF and steady release of nutrients from applied compost. Investigations from similar studies for Onion (Ortega-García et al., 2015), Celosia (Komolafe et al., 2021) and Okra (Kayode et al., 2018) have proven increase in crop growth and yield may be assigned to symbiotic associations of AMF and compost mineralization.

Conclusion

Short-term application of compost with and without mycorrhizal inoculation at transplanting enhanced plant growth, uptake of essential nutrient and improved soil productive capacity. The effect of combined application of compost and AMF inoculation positively influence macronutrients in the soil, plant growth, nutrient uptake and root colonization. Since compost is an organic amendment, combination with AMF could be a management strategy to improve soil productive quality. This could be recommended to farmers since it is environmental friendly and requires no specialized skill for its application. Therefore a long-term experiment should be conducted since longer time allows more decomposition of compost.

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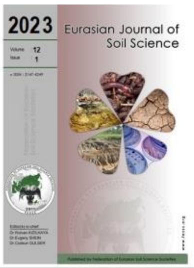

The effects of ammonium phosphate fertilization on yield and yield components of Mustard varieties in chernozem soil

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Abstract

Mustard seed is primarily used in the food or condiment industries in the form of either ground seeds or oil, and plays a significant role in agriculture. Especially in the intensive agricultural system where chemical fertilizers are used, little is known the impact of ammonium phosphate (Ammophos, 12% N, 52% P_2O_5) fertilizer applications on the yield and yield component of mustard under chernozem soil conditions. The objective of this study was to investigate the effects of seven doses of ammonium phosphate fertilizer applications on the seed yield and yield components of two different mustard varieties [Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.)] under chernozem soil conditions in Northern Kazakhstan. According to field experiment results, there were significant differences among the treatments in relation to yield and yield components (oil content, dry matter accumulation, NPK uptake, NPK contents in seeds) of mustard varieties. The higher seed yield for the $N_{34.6}$ P_{150} treatment in Rushen and $N_{41.5}$ P_{180} treatment in Profi than for any of the other rates of ammonium phosphate fertilizer application under the agro-ecological conditions of Akmola region, Northern Kazakhstan.

Keywords: Mustard, chernozem soil, nutrients, fertilizer, ammonium phosphate.

Introduction

Mustard is an annual, cool-season specialty cash crop that has a short growing season and is commonly grown in rotation with small grains. Mustard is the name given to two closely related species in the Brassica family. There are over 40 varieties of mustard worldwide, and the most popular are black, brown, and white mustard seeds. Two types of mustards such as brown mustard (Brassica juncea Czern) and yellow mustard (Sinapis alba L.) are cultivated in Kazakhstan. Chernenok et al., (2017) provided a critical review on the necessity to study mustard in the steppe zone of Kazakhstan, where the biological features of mustard allow growing under arid and harsh climatic conditions for seed, also as a forage and green manure. Importantly, mustard is undemanding to soil conditions and heat which is the advantage of growing mustard in the steppe zone of Kazakhstan. Mustard is widely used as a good precursor for cereal crops because it prevents soil erosion, and it is a natural fumigant against weeds, diseases, and soil-born pests. During the introduction of mustard to Kazakhstan's forest-steppe zone and irrigated land conditions, the primary attention was paid to mustard biology, breeding, cultivation technology, and crop fertilizers (Ivankova, 2004; Grishanov, 2009).

Soil conditions affect the productivity of mustard seeds and green mass, which provide nutrients and moisture. Soil fertility depends on the primary nutrient status of the soil and the application of fertilizers. Other studies were carried out in this direction, making it possible to study in the context of a regional character. Some of them showed that the application of fertilizers for mustard affects the crop yield and its

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profitability, which is a decisive factor (Chand et al., 2006; McKenzie et al., 2006; Sefaoğlu et al., 2021). Amongst many others, the nutritional requirements of the crop are considered to be the most important factor.

Nitrogen and phosphorous fertilizers play a vital role in enhancing mustard yield, in that they form the basis of photosynthetic processes, cell growth, metabolism, and protein synthesis (Chapin et al., 2000). Not only the amount of the nutrients in the soil but also the nutrient balance is important for producing agricultural plants in a high quality and quantity (Sefaoğlu et al., 2021). A high rate of N application increases leaf area development, improves leaf area duration after flowering and increases overall crop assimilation, thus contributing to increased seed yield (Wright et al., 1988). Patel et al. (2004) reported that as the dose of nitrogen increased the oil content of Indian mustard decreased and its seed yield increased. Phosphorus is the second most deficient nutrient element after nitrogen in terms of plant productivity in soils. Rodríguez et al. (2000) reported that the leaf area decreased by 83% and photosynthesis efficiency decreased by 50% in the plants grown under phosphorus stress.

Chernozem soils in North Kazakhstan occupy 25.3 million ha and are the most productive soils of the country. An area of approximately 11 million ha of Chernozem soil was planted annually with spring wheat (Triticum aestivum L) during the Soviet period when the political aim of a rapid increase in grain production was achieved by indiscriminate plowing of as large an area of virgin lands as possible (Karbozova–Saljnikova et al., 2004). Chernozem soils are a valuable resource because of their extent and because they are fertile. Chernozems must be properly managed and protected for efficient and sustainable productivity. They have been researched in the past but mainly as a soil-geographic resource. Further study is needed to quantify and expand their value in production and assure environmental sustainability (Saparov, 2014). Many factors are involved in producing a high yield of mustard. Although climatic factors such as rainfall and temperature cannot be controlled, many other critical components of the production system like fertilizer application can be carefully managed. High mustard yields require maintenance of agricultural practices to meet the needs of the rapidly growing crop. As the demand for high yield and oil content closer examinations of the role of proper agricultural practices are needed.

This study was carried out to evaluate the effects of different rate of ammonium phosphate fertilizer application on yield and yield components (oil content, dry matter accumulation, NPK update and NPK contents in seeds) of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties in chernozem soil of Northern Kazakhstan.

Material and Methods

Study Area

The experiment was performed at LLP Nikolskoye, Bulandinsky district, of the Akmola region, Northern Kazakhstan (52”13’15”N, 70”32’29”E) during the growing season 2020-2021 with a view to finding out the 2 different mustard variety as well as determining the effects of different P fertilizer doses on mustard yield and yield components. This region is characterized by a semi-arid climate. The locations of the evaluations were characterized by the continental climate (large daily and annual fluctuations in air temperature, characterized by cold winters and long hot summers), the air temperature reaches minimum values in January (-15,5^{0}C), and maximum values in July (17,5^{0}C), the average annual temperature is +2.4 ^{0}C and an annual amount of precipitation is 365 mm.

Soil

The main soil type, which is typical for the region, is calcic chernozem or carbonate chernozem soil. The thickness of this chernozem is between 50 cm and 100 cm. There is a horizon with a concentration of secondary carbonates (calcic horizon). The $CaCO_3$ accumulations are in the size of clays or silts. The Soil Taxonomy (USDA, 1975) also admits the presence of a calcic horizon in mollisol with a mineral horizon that is marked by a prefix calci- in the name of the soil. The soil belongs to the general soil type of calcic chernozem. The soil pH was 8.0-8.1, and calcium carbonate ($CaCO_3$) concentration was 0,9%, soil organic matter was 3.8%, total N was 0.25-0.30%, available phosphorus was 15-20 mg/kg and exchangeable potassium was 350-500 mg/kg.

Mustard

The objects of the research were 2 mustard variety, Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.), choose for use. Characteristics of mustard varieties are given Table 1. The characteristics of these mustard varieties allow cultivation under the given conditions and their biological characteristics correspond to cultivation in the studied soil-climatic zone.

Table 1. Characteristics of mustard varieties (Sahay et al., 2015; Singh and Thenua, 2016)

Characteristics of mustard varieties	Rushen (Brassica juncea (L.) Czern.)	Profi (Sinapis alba L.)
Year of release	1992	2011
The vegetation period (days)	82-98	110
The yield of mustard seeds, c/ha	16,0	20,9
Oil contents, %	37,7	37,4
Susceptibility of mustard varieties to diseases	Slightly susceptible to downy mildew	Slightly susceptible to powdery mildew, clubroot of crucifers, weakly to alternaria
Susceptibility of mustard varieties to pests	Very susceptible to cabbage flea	Stable sugar beet nematode
The content of erucic acid, %	None	Available
The content of oleic acid, %	36,0	26,0
The content of linoleic acid, %	19,4	32,0

Treatments and Experimental design

The field experiment was performed using a completely randomized block design with three replications during the 2020-2021. The experimental unit was 54 m^2 (9 m x 6 m). The sources of fertilizers used were ammonium phosphate (Ammophos, 12% N, 52% P_2O_5). The experiment was performed with the following seven treatments of agricultural practices given in Table 2.

Table 2. Phosphorus fertilizer levels in field experiment

T1	P_0	Control
T2	$N_{13.8}$ P_{60}	115.4 kg ammonium phosphate/ha (13.8 kg N/ha, 60 kg P_2O_5/ha)
T3	$N_{20.8}$ P_{90}	173,1 kg ammonium phosphate/ha (20.8 kg N/ha, 90 kg P_2O_5/ha)
T4	$N_{27.8}$ P_{120}	230,8 kg ammonium phosphate/ha (27.8 kg N/ha, 120 kg P_2O_5/ha)
T5	$N_{34.6}$ P_{150}	288,5 kg ammonium phosphate/ha (34.6 kg N/ha, 150 kg P_2O_5/ha)
T6	$N_{41.5}$ P_{180}	346,2 kg ammonium phosphate/ha (41.5 kg N/ha, 180 kg P_2O_5/ha)
T7	$N_{48.5}$ P_{210}	403.8 kg ammonium phosphate/ha (48.5 kg N/ha, 210 kg P_2O_5/ha)

The land was disk ploughed, harrowed, and leveled with a tractor. Then mustard was sown (10 kg/ha) with a Bourgault 3710 sowing complex. Fertilizer was applied using grain drill. During the field experiment, same agricultural practices used in same plot of experiment and all the cultural practices regarding fertilization, irrigation, weed control, and pest and disease management were conducted as standard regional cultivation practices. Two mustard varieties (Rushen and Profi) were combined with seven phosphorus fertilizer treatments.

Observed parameters

Plant samples were taken from different phenological periods of the mustard plants. Observed analyses parameters in mustard plants were seed yield, oil content, dry matter accumulation, NPK update and NPK contents in seeds. All parameters were measured according to Jones (2001).

Results and Discussion

In this experiment conducted under rainfed condition, the soil moisture content at the phenological periods of Rushen mustard varietry was 25.9 mm (Pre-sowing); 9.6 mm (Budding), 25.2 mm (Flowering) and 9.5 mm (Harvesting) at 0-20 cm soil depth while it was determined that 27.2 mm (Pre-sowing); 12.2 mm (Budding), 15.3 mm (Flowering) and 9.3 mm (Harvesting) in Profi mustard variety. Both Rushen and Profi mustard variety, it was determined that the moisture content in surface soil (0-20 cm) were higher than in 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm soil depths (Figure 1). In Figure 1, the reserves of productive soil moisture in a meter layer pre-sowing mustard varieties totally 169 mm. It was determined that during the experiment there was a lack of productive soil moisture in the under mustard crops under rainfed condition. Mustard crop is grown in the areas receiving 625-1000 mm yearly rainfall. But, annual amount of precipitation is 365 mm in this research area.

Seed yield and Oil content

In the present study, the seed yield of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties increased in response to ammonium phosphate fertilizer application relative to the control (T1) and lower rates of application, with maximum yields (2.07–2.22 t ha^{-1}) being attained at the T5 and T6 rate of ammonium phosphate fertilizer application in both varieties (Figure 2).

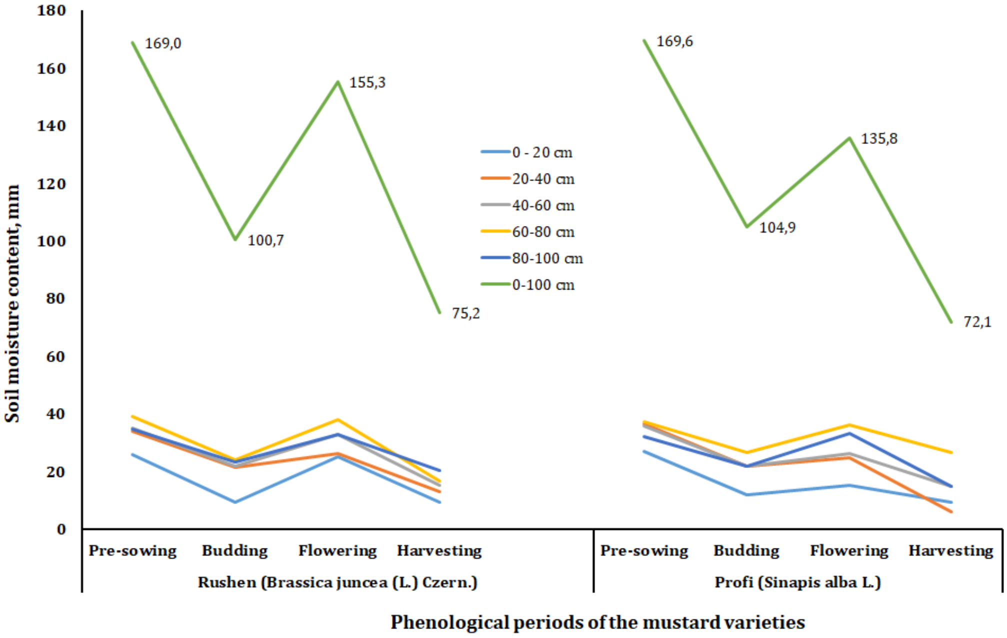

Figure 1. Pattern of soil moisture content during phenological periods of the mustard varieties

Similar yields were reported by other authors (Hocking et al., 1997; Kumar et al., 1997; Nurmanov et al., 2019). Gammellvind et al. (1996) reported a higher seed yield, varying from 2.8 to 4.8 t ha^{-1}, in winter oilseed rape. He also noted a decrease in seed yield at the higher rate of fertilizer application, a result similar to that found in the present study and also by Hocking et al. (1997). The higher seed yield for the T5 treatment in Rushen and T6 treatment in Profi than for any of the other rates of ammonium phosphate fertilizer application. These differences between Rushen and Profi in these yield-determining characteristics were probably associated with significant differences in the leaf area and robust root system of these treatments. This conclusion is supported by the findings of previous studies (Scott et al., 1973; Allen and Morgan 1975; Tayo and Morgan, 1975). The rates of ammonium phosphate fertilizer application affected the oil content in Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties (Figure 2). In Rushen, the highest oil content of 30.4% was found in T5, while in Profi the highest oil content was 37.5% was in T4, this value being significantly higher than the values found in all other treatments, where the difference was statistically non-significant. The higher rates of ammonium phosphate fertilizer application (T6 and T7) reduced the oil content relative to the lower rates of ammonium phosphate fertilizer application. Similar results have been reported in oilseed rape (Asare and Scarisbrick, 1995) and canola (Hocking et al., 1997).

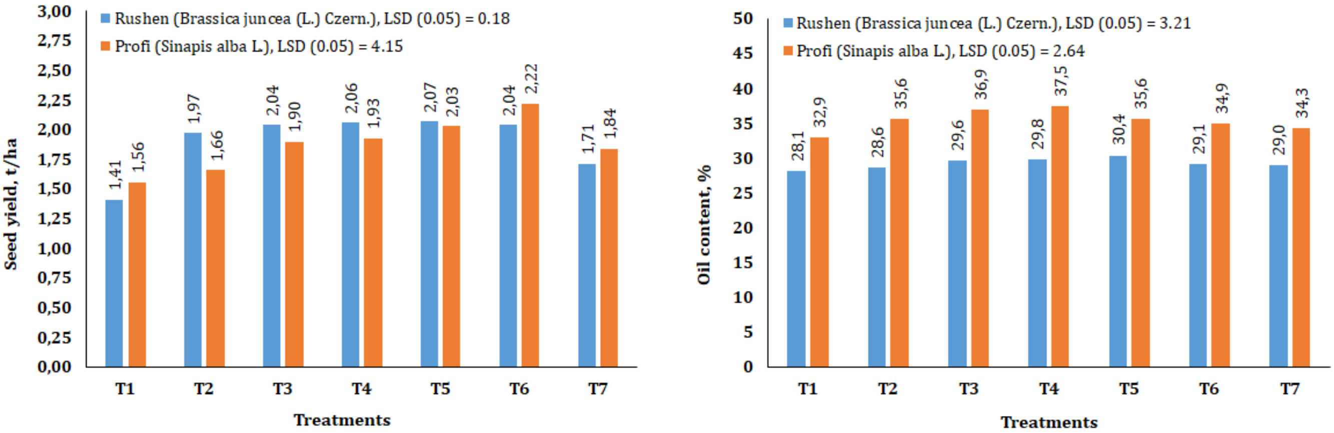

Figure 2. Effect of rate of ammonium phosphate fertilizer application on seed yield (a) and oil content (b) of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties

Dry matter accumulation

Generally, total dry matter accumulation continued to increase until the full ripeness in Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties (Figure 3) at all treatments. Similar growth curves for total dry matter accumulation in a crops were reported by others (Scott et al., 1973; Allen and

Morgan, 1975; Kjellstrom, 1993; Cheema et al., 2001). The highest rate of ammonium phosphate fertilizer application (T7) gave significantly higher total dry matter than the control (T1) or the lower rates of fertilizer application (T2–F6) in Rushen and Profi mustard varieties (Figure 3). At full ripeness phenological stage of Rushen, the average total dry matter yield was 92.90 in T1, 269.70 in T2, 274.80 in T3, 260.10 in T4, 321.30 in T5, 316.6 in T6 and 414.90 g/100 plants in T7. At full ripeness phenological stage of Profi, the average total dry matter yield was 156.60 in T1, 226.70 in T2, 262.90 in T3, 215.40 in T4, 313.20 in T5, 352.6 in T6 and 387.50 g/100 plants in T7. In these experiments, marked differences in total dry matter yield among different rates of fertilizer application. Kumar et al. (1997) also reported higher total dry matter production with increased rate of fertilizer application. Thus, at any given harvest, the dry matter accumulation is a physiological index closely related to the photosynthetic activity of leaves.

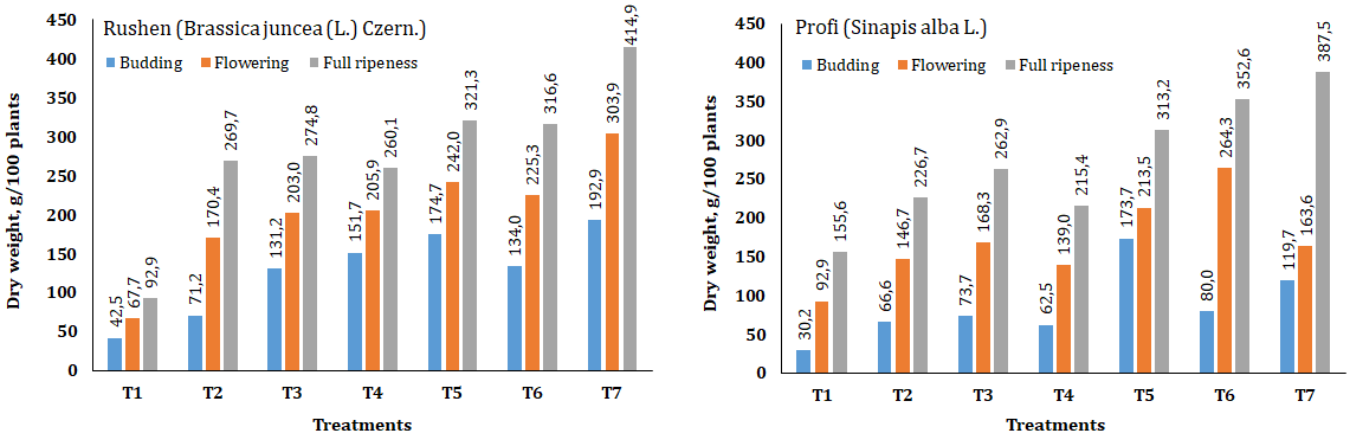

Figure 3. Effect of rate of ammonium phosphate fertilizer application on dry weight of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties

Nutrient contents in seeds

The effects of different rate of ammonium phosphate fertilizer application on nitrogen, phosphorus, and potassium contents in in seeds of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties are presented in Figure 4. All of the above parameters were significantly influenced by different rate of ammonium phosphate fertilizer application compared to the control (T1). The total N contents in Rushen and Profi mustard varieties varied from 1.02 to 1.31% (highest content at T2 treatment) and 0.76 to 1.36 % (highest content at T6 and T7 treatments), respectively. The total phosphorus contents in Rushen and Profi mustard varieties varied from 0.54 to 0.65 % (highest content at T6 treatment) and 0.56 to 0.78% (highest content at T7 treatment), respectively. Finally, the total K contents in mustard varieties ranged from 1.26 to 1.47 % for Rushen (highest content at T6 treatment) and 0.86 to 0.93% for Profi (highest content at T6 treatment) under different rate of ammonium phosphate fertilizer application. Al-Taey et al. (2018) recorded that the application of fertilizers can improve plant growth and increase of N, P and K contents in tissue and their uptake. Gülser et al (2021) and Kızılkaya et al. (2022) reported that fertilizers consist of N, P, K increase the uptake and utilization of nutrients by grain crops.

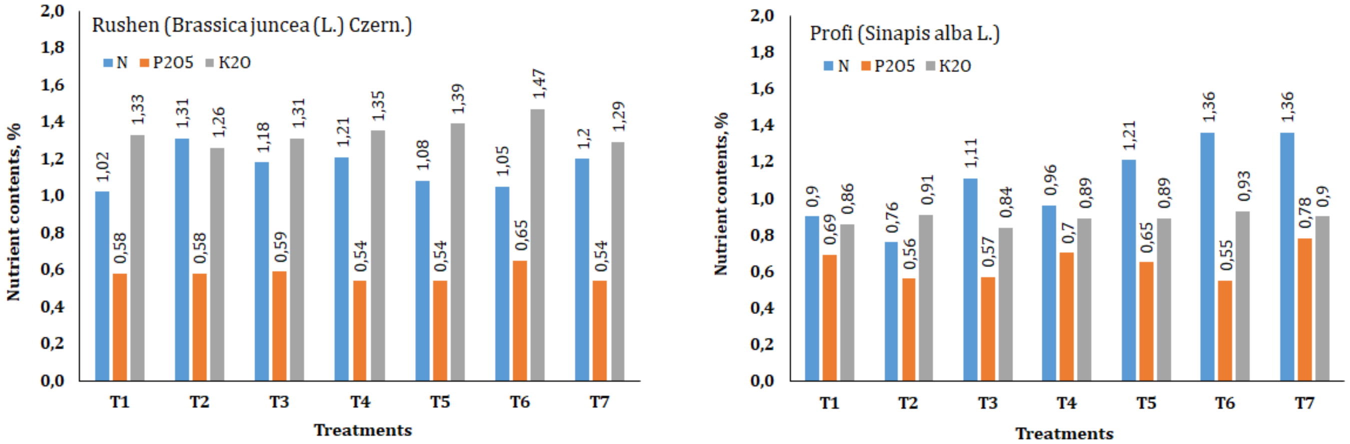

Figure 4. Total N, P and K contents in seeds of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties affected by different rate of ammonium phosphate fertilizer application (LSD$_{0.05}$ value: 0.10 N, 0.03 P2O5 and 0.04 K_2O for Rushen, 0.70 N, 0.03 P_2O_5 and 0.03 K_2O for Rushen)

Nutrient uptake

Total N, P and K uptake in aboveground plant parts of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties under different rate of ammonium phosphate fertilizer application are shown in Figure 5. Total N uptake was enhanced under ammonium phosphate fertilizer application compared with control (T1). The total N uptake by Rushen and Profi mustard varieties varied from 14.4 to 25.8 kg ha^{-1} (highest uptake at T2 treatment) and 12.9 to 26.4 kg ha^{-1} (highest uptake at T6 treatment), respectively. The total N uptake during the experiment was higher for the ammonium phosphate fertilizer applications than control. Phosphorus uptake in both Rushen and Profi mustard varieties was greater under ammonium phosphate fertilizer application compared with control. The total phosphorus uptake by Rushen and Profi mustard varieties varied from 6.6 to 13.3 kg ha^{-1} (highest uptake at T6 treatment) and 8.2 to 13.2 kg ha^{-1} (highest uptake at T5 treatment), respectively. Finally, the total K uptake by mustard varieties ranged from 17.9 to 29.4 kg ha^{-1} for Rushen (highest uptake at T5 treatment) and 12.5 to 20 kg ha^{-1} for Profi (highest uptake at T6 treatment) under different rate of ammonium phosphate fertilizer application. These results were in agreement with previous studies (Pan et al., 2012) that reported that yield components were affected by the fertilizations, and consequently, crop yields were usually greater depending on the soil fertility (Hossain et al., 2005). A close positive correlation between nutrient uptake and crop yield has also been reported previously (Witt et al., 2000). The highest mustard yields were observed at theT5 and T6 treatments, due to their correspondingly higher N, P and K uptakes. In addition to the nutrient uptakes, consideration was also given to their interactions. Many researchers have observed the complicated interactions among N, P and K in crop productivity (Yang et al., 2007). In our study, P and K uptake was higher when applied with N, as evidenced by greater P and K accumulation in ammonium phosphate fertilizer application than in control, which clearly indicates the synergistic effect of N on P and K uptake. Our results revealed that T5 ($N_{34.6}$ P_{150}) for Ruslen and T6 ($N_{41.5}$ P_{180}) for Profi application was best at improving the yield and nutrient accumulations for fertilization.

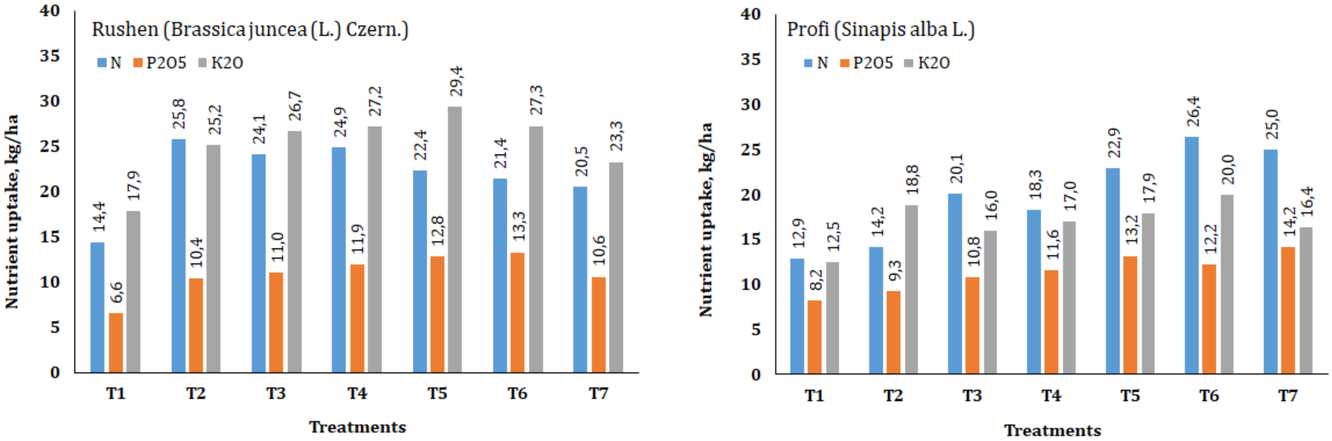

Figure 5. Total N, P and K uptake (kg ha^{-1}) by aboveground parts of Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.) mustard varieties affected by different rate of ammonium phosphate fertilizer application

Conclusion

Two mustard varieties (Rushen (Brassica juncea (L.) Czern.) and Profi (Sinapis alba L.)) and different rate of ammonium phosphate fertilizer application were used to investigate effects on yield and yield parameters of mustard under chernozem soil conditions in the Kazakhstan. It was evident that increased levels of ammonium phosphate resulted higher growth performance in all mustard varieties than control. The higher seed yield for the T5 treatment ($N_{34.6}P_{150}$) in Rushen and T6 treatment ($N_{41.5}$ P_{180}) in Profi than for any of the other rates of ammonium phosphate fertilizer application. The higher rates of fertilizer application (T6 and T7) reduced the oil content relative to the lower rates of fertilizer application.

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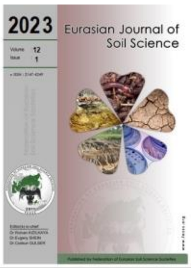

Variability of major soil properties of a fallow-acidic-level upland with high and multiple spatial resolutions

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Abstract

Variation of the soil attributes of a land in an area is dependent on topography, time, climate, parent material, land use land cover, land management, distance and scale. This variation affects the representation of soil of a land in an area. The study aimed to assess the variations in the representation of major soil properties of a unique fallow-acidic-undisturbed-level upland in different spatial resolutions of soil sampling. A fallow and level upland of 1500 m^2 as separately gridded with the spacing of 5mx5m, 10mx10m and 15mx15m and geo-referenced surface (0-20 cm) soil samples were collected from the corner of each grid. The collected soil samples were analyzed for texture (Tx), organic carbon (OC), pH, total N (TN), available P (AP), exchangeable K (exch K), available S (AS), available Fe (AFe), available Zn (AZn) and available Mn (AMn) in soil. Statistical and geospatial analyses of the dataset were done with the relevant softwares. For the nutrients TN, AP, AZn and AFe, coefficients of variation (CV) showed a trend of increment across high-medium-low spatial resolutions, and their variability ranked as AZn (mean CV=104.03%, great variation)>AFe (mean CV=41.67%, moderate variation)>AP (mean CV=20.32%, moderate variation)>TN (mean CV=4.92%, low variation) based on average CV of three spatial resolutions of sampling. In case of other soil attributes, no particular trend of increment or decrement was observed across the resolutions and their variability was moderate except for pH which had low variability. Their variability ordered as exch K (mean CV=35.17%)>AS (mean CV=34.98%)>SOC (mean CV=31.71%)>Tx (mean CV=31.17%)>AMn (mean CV=30.10%)>Soil pH (mean CV=6.96%). Rationale correlations were observed between some soil attributes (pH *vs* AZ, AFe, OC; Tx *vs* TN, AP; Exch K *vs* AZn *vs* AFe; OC *vs* Exch K, AZn, AFe) with different degrees of associations (r), and increased trend in r value was found across the resolutions of high-medium-low except for pH and Tx. Different spatially gradient structures of the ordinary krigged interpolated maps were observed for different soil properties and for different spatial resolutions. Quantitatively, calculated (from semivariograms) nugget effects of 0-100% indicated that spatial dependency of studied soil properties could be very strong to very weak. The heterogeneity of soil in the upland as revealed by our results would assist scientists or farm managers to use or compare scale-dependent soil data wisely and precisely.

Keywords: Geospatial, soil attributes, correlation, heterogeneity, map.

Introduction

Soils of a land of an area vary across distance and over time. This variation (spatial and/temporal) of soil constructs soil heterogeneity affected generally by the soil forming factors (Jenny, 1941), and also by some specific aspects as land use land cover (Zhang et al., 2015; Panday et al., 2019; Sharma and Sood, 2020), soil series (Behera and Shukla, 2014), soil category (Usowicz and Lipiec, 2017; Delbari et al.,, 2019), soil depth (Behera et al., 2016; Negassa et al., 2019), parent material (Dengiz et al., 2013; Şenol et al., 2018) locations

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(Reza et al., 2016; 2017), tillage (Özgöz et al., 2010), soil erosion (Salviano, 1996), scale or size of the area (Wang et al., 2017), and land management (Shukla et al., 2016; Metwally et al., 2019). Conversely, this variability affects application of irrigation water (Zhang et al., 2013), nutrient management (Fang et al., 2020), crop growth and yield (Usowicz and Lipiec, 2017; Su et al., 2018; Castellini et al., 2019). Soil variability assessment is also needed for food safety and environmental modeling (Hangsheng, 2005; Bhunia et al., 2018). For carrying out a study on soil in an area, sampling of soil (an invasive method) is usually done to represent the land of an area. This sampling of soil of an area is done by random sampling with more or less well distribution between sampling points (Wang et al., 2017; Reza et al., 2017; Bhunia et al., 2018; Niederberger et al., 2019) or by grid-basis maintaining a specific distance between sampling points (e.g., Negassa et al., 2019). The variable distance between sampling points can be designated as spatial resolution of soil sampling (soil sampling densities). In regards to grid-basis sampling, different spatial resolutions of soil samplings such as 3 m × 3 m (Negassa et al., 2019), 50 m × 50 m (Bogunovic et al., 2014), 60 m × 60 m (Su et al., 2018), 70 m × 70 m (Delbari et al., 2019) were used in the previous studies to represent various study areas and to study spatial variability of soil properties in the respective spatial resolution. This spatial resolution of soil sampling is supposed to affect the representation of soil of a particular land in an area thereby affecting the variability of soil properties of study area. Study regarding soil properties variability in a unique land with multiple spatial resolutions is rare. Keeping other factors unchanged, a well aerated, fallow, anthropologically undisturbed, acidic and topographically leveled land with humid subtropics needs to be studied for variability of major soil properties as a function of spatial resolutions of soil sampling. The hypothesis of this study was if the soil properties of the same unit of land vary as a function of the sampling densities or spatial resolution of sampling. The research question of the study was how the major soil properties of unique unit upland are represented differently with different soil sampling densities (referred as spatial resolution of soil sampling). The information would assist the soil scientists or soil surveyors or farm managers to compare or use soil data logically and precisely. Therefore, the present study was systematically designed to assess the variability of major soil properties of a unique unit of upland depending on spatial resolution of soil sampling.

Material and Methods

Study area and soil sample collection: Geo-referenced (averaging three GPS readings) surface soil (0-20 cm) samples were collected from upland (1500 m^2) with the assistance of GPS device in the three spatial resolutions making grids across the land located in Sylhet district of Bangladesh (Figure 1).

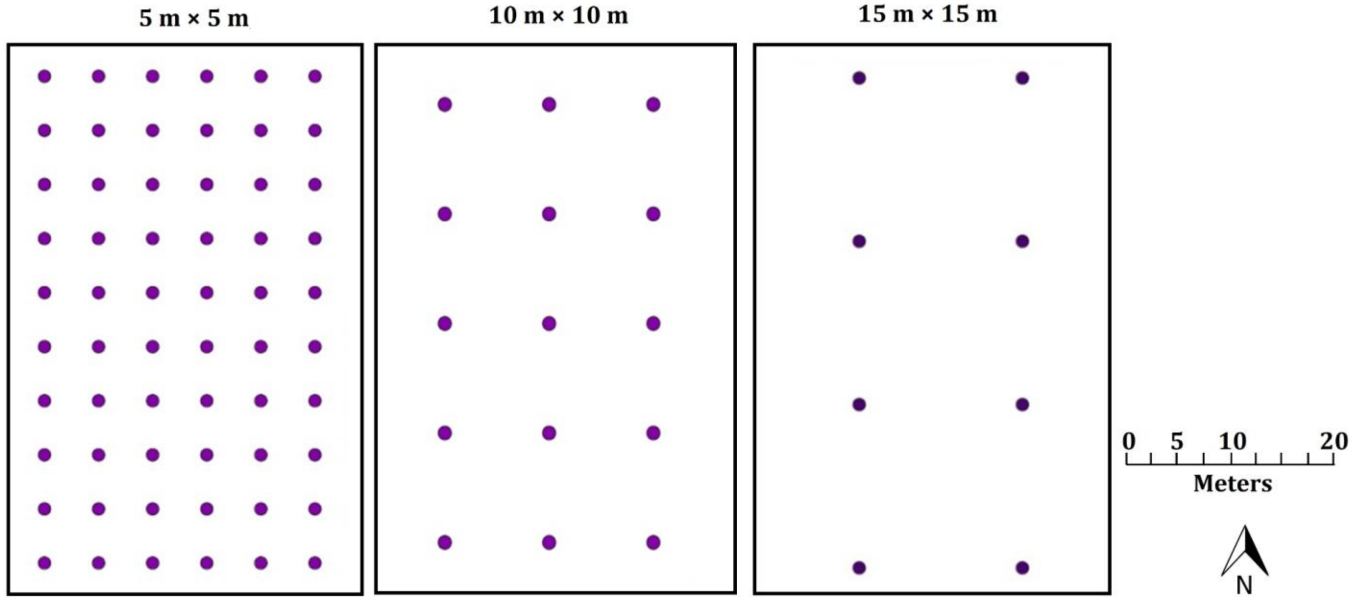

Figure 1. Sampling points in various spatial resolutions (5 m × 5 m, 10 m × 10 m, 15 m × 15 m; from left to right) in the study upland located in Bangladesh

The grids were at the spacing of 5 m × 5 m, 10 m × 10 m, and 15 m × 15 m. Soil samples were collected from the corner of grids (Figure 1). Errors on certain points of GPS readings were adjusted with the known values (distance) between points. The land was a fallow land which was anthropologically undisturbed for about 1.5 years. The area received an average annual air temperature of 24.8 °C, an average annual rainfall of 3876 mm. The land of the area is situated at 35 m above sea level (masl), which is topographically leveled. The samples were collected during dry season (November) of the year 2018 from fallow land with very thin grass layer.

Soil sample processing and analysis

The collected soil samples were brought to the laboratory and dried in the air by spreading them over the sheet of brown paper. Then they were ground and passed through 10 mesh sieve (2 mm), and kept in small plastic pot (upon labeling) for further analyses. The analytical methods followed for the determination of soil attributes are presented in Table 1.

Table 1.The analytical methods followed for the determination of soil attributes

Soil Parameter Analyzed	Unit	Methods of Analysis Followed
Particle Size Analysis	% of individual fractions	Hydrometer method (Bouyoucos, 1962)
Soil pH	____	Glass electrode pH meter method (soil: water ratio being 1: 2.5) (Jackson, 1973)
Organic carbon	%	Wet oxidation method (Walkley and Black, 1934)
Total Nitrogen (TN)	%	Micro-Kjeldahl method (Bremner and Mulvaney, 1982)
Available Phosphorus (AP)	mg/kg	Bray and Kurtz method (Bray and Kurtz, 1945)
Exchangeable Potassium (ExchK)	$cmol_c/kg$	Ammonium acetate method (Jackson, 1973)
Available Sulphur (AS)	mg/kg	Calcium Bi-phosphate Extraction Method (Fox et al., 1964)
Available Zink (AZn)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)
Available Iron (AFe)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)
Available Manganese (AMn)	mg/kg	DTPA Extraction method (Lindsay and Norvell, 1978)

Statistical analyses of the dataset

Summary statistics of mean, standard deviation (derived coefficient of variation, CV), minimum and maximum (i.e., range) were found out for soil parameters of total N (TN), available P (AP), exchangeable K (Exch K), available S (AS), available Zn (AZn), available Mn (AMn), available Fe (AFe), soil texture (individual soil fractions), pH and organic carbon (OC). This statistical analysis was done with the spreadsheet. Pearson correlation matrix (with the level of significance) of the said soil parameters was found out using the statistical package of SPSS (version 16). Zhang et al. (2007) mentioned that variability of a soil property can be described by coefficient of variation (CV). A class of CV (CV<10%: Low variability; CV=10-90%: Moderate variability; CV>90%: Great variability) as provided by Jiang et al. (2003) and cited by Zhang et al. (2007) was used to denote the degree of variation of soil attributes studied.

Geostatistical analyses of the dataset with various spatial resolutions

Interpolations from the sampling points of respective sampling densities (here referred as spatial resolutions) for creating continuous surface maps of the soil attributes onto the land of interest by ordinary kriging (Journel and Huijbregts, 1978; Clark, 1979) method were performed and the classifications of the soil parameters were done with the same class intervals for making comparisons. ArcGIS 10.3 was used for this analysis. During the geostatistical analyses, fitted semivariograms (Goovaerts, 1997) with any of suited models (Stable, J-bessel, K-bessel, Hole effect, Pentaspherical) for the studied soil parameters were inspected to derive nugget effects (nugget/sill ratio). Nugget/Sill ratio class (<25%: strong autocorrelation, 25-75%: moderate autocorrelation, >75%: low autocorrelation) given by Cambardella et al. (1994) was used to indicate the spatial correlations of the studied soil parameters in the land for each spatial resolution of soil samplings. The data normality was checked visually (normal or near-normal distribution) by histograms. The root mean squired errors (RMSE) were checked (for lower values) and recorded from the summary report of the analysis. The report of Ettema and Wardle (2002) was also used for the quantification as well as explanation of spatial variability and heterogeneity of the soil attributes.

Results

Statistical variability of major soil propertiesat various spatial resolutions

Classical statistics of the soil attributes for the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m are presented in the Table 2. Soil texture (as indicated by Sand: Clay) ranged 3.22:1 to 21.09:1, 5.08:1 to 11.66:1 and 4.11:1 to 9.23:1, respectively across the resolutions. In the three spatial resolutions (high, medium, low), its corresponding coefficients of variation (CV) were 41.69, 25.04 and 26.77%, respectively. Particular trend of CV (high-medium-low or vice versa) was not observed across the spatial resolutions, although its higher CV (41.69%) was observed in high resolution. Soil organic carbon ranged 0.60-2.20, 0.67-2.19 and 0.81-2.19%, respectively across the spatial resolutions. In the three resolutions, the corresponding CVs were 34.35, 30.10, and 30.67%, respectively. Particular trend of its CV was not observed across the spatial resolutions, although higher CV (34.35%) was in case of high resolution. Regarding soil pH, it ranged from 4.1

to 5.8, 4.1 to 5 and 4.1 to 5.1 for high, medium, and low resolutions, respectively. In the three resolutions, its corresponding CVs were 7.33, 5.40, and 8.16%, respectively. In contrast to soil texture and SOC, its higher CV (8.16%) was found for low resolution, although no particular trend of CV was observed across the spatial resolutions. Total nitrogen spanned from 0.079 to 0.091, 0.079 to 0.09, and 0.08 to 0.09%, respectively with CV values of 4.42, 4.77, and 5.56%, respectively. Its CV increased gradually with the decrease in spatial resolutions. In case of available phosphorus, its range varied from 6.8 to 17.3, 6.8 to 16.1, and 7.5 to 15.9 mg/kg, respectively across the resolutions. Its corresponding CVs were 16.59, 19.99, and 24.39%, respectively. Similar to TN, its CV increased gradually with the decrease in spatial resolutions. Exchangeable potassium ranged 0.06-0.24, 0.07-0.19, and 0.06-0.19 cmol$_c$/kg, respectively across the three resolutions. Its corresponding CVs were 32.93, 30.92, and 41.66%, respectively. Contrary to TN and AP, no particular trend of CV for Exch K was observed across the resolutions. Available sulphur in the three spatial resolutions of soil sampling spanned from 4.7 to 51.4, 4.7 to 42.2, and 14.3 to 42.2 mg/kg, respectively. Its corresponding CVs were 29.48, 38.63, and 36.84%, respectively. Although higher CV of available S (38.63%) was found in moderate spatial resolution, no particular trend of CV was observed across the resolutions.

Table 2.Descriptive statistics of soil texture, organic carbon, pH, total N, available P, exchangeable K, available S, available Zn, available Fe, and available Mn

Resolutions	5 m×5 m		10 m×10 m		15 m ×15 m		Mean
Soil variables	CV (%	Range	CV (%)	Range	CV (%)	Range	CV
Tx	41.69	3.22:1 - 21.09:1	25.04	5.08:1 - 11.66:1	26.77	4.11:1 - 9.23:1	31.17
OC (%)	34.35	0.60 - 2.20	30.10	0.67 - 2.19	30.67	0.81 - 2.19	31.71
Soil pH	7.33	4.10 - 5.80	5.40	4.10 - 5.00	8.16	4.10 - 5.10	6.96
TN (%)	4.42	0.08 - 0.09	4.77	0.08 - 0.09	5.56	0.08 - 0.09	4.92
AP (mg/kg)	16.59	6.80 - 17.30	19.99	6.80 - 16.10	24.39	7.50 - 15.90	20.32
Exch K (cmol$_c$/kg)	32.93	0.06 - 0.24	30.92	0.07 - 0.19	41.66	0.06 - 0.19	35.17
AS (mg/Kg)	29.48	4.70 - 51.40	38.63	4.70 - 42.20	36.84	14.30 - 42.20	34.98
AZn(mg/kg)	75.41	0.21 - 4.53	107.93	0.28 - 4.53	128.74	0.31 - 4.53	104.03
AFe (mg/kg)	35.10	32.00 - 167.00	43.06	37.00 - 167.00	46.84	42.00 - 165.00	41.67
AMn (mg/kg)	31.33	12.10 - 52.20	21.97	12.90 - 34.50	36.99	17.70 - 52.20	30.09

Tx= Soil texture (Sand/Clay); OC=Organic Carbon; TN= Total nitrogen; AP= Available phosphorus; Exch K= Exchangeable Potassium; AS= Available Sulphur; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; CV= Coefficient of variation

Available Zn ranged from 0.21 to 4.53, 0.28 to 4.53, 0.31 to 4.53 mg/kg, respectively. The corresponding CVs were 75.41, 107.93, and 128.74%, which showed a particular trend of increment of CV across high-medium-low spatial resolutions. Available Fe ranges from 32-167, 37-167, and 42-165 mg/kg for three spatial resolutions, respectively. Similar to available Zn, CVs of available Fe in the said resolutions were 35.10, 43.06, and 46.84%, respectively which also demonstrated a trend of increment of CV across high-medium-low spatial resolutions. For available Mn, it ranged from 12.1 to 52.2, 12.9 to 34.5, and 17.7 to 52.2 mg/kg, respectively (Table 2). In the three resolutions, the corresponding CVs of available Mn were 31.33, 21.97 and 36.99%, respectively of which higher one was in case of low resolution with no particular trend (increment or decrement) of CVs across the resolutions.

Considering the overall (average CVs of all spatial resolutions) variations of each soil attributes, all attributes showed moderate variability (CV within the range of 10-90%) except TN (CV = 4.92%, low variability), pH (CV = 6.96%, low variability) and AZn (CV = 104.03%, great variability).

Variations in correlations matrix of soil attributes as a function of sampling density

Data presented in Table 3 shows that soil pH is significantly and negatively correlated (r=-0.32** to -0.41**) with available Zn, available Fe and OC. Available P has significant strong correlation (r=0.94**) with total N. Mineral nutrient elements exchangeable K, available Zn and available Fe have positive and significant correlations (r=0.27-0.66) with each other.

Data presented in Table 4 shows that SOC positively correlated with exchangeable K (r=0.60*), available Zn (r=0.61**) and available Fe (r=0.66**) in soil. Soil available P has strong positive correlation with total N (r=0.92**). Strong correlation (r=0.68**) exist between exchangeable K and available Zn in soil. Again, exchangeable K is positively correlated (r=0.56*) with Fe in soil. Similarly, micronutrient available Zn is positively correlated (r=0.72**) with available Fe in soil. And, SOC has moderately positive correlation (r=0.60* to 0.66**) with exchangeable K, available Zn and available Fe.

Table 3. Pearson correlation matrix between the soil properties with 5m x 5m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.94**	1.00								
ExchK	-0.14	-0.11	1.00							
AZn	-0.16	-0.17	0.39**	1.00						
AFe	0.00	0.00	0.27*	0.66**	1.00					
AMn	-0.17	-0.04	0.08	0.12	0.20	1.00				
AS	0.12	0.07	0.02	0.14	0.07	0.06	1.00			
SOC	-0.03	-0.06	0.26*	0.37**	0.48**	-0.15	0.05	1.00		
pH	0.21	0.23	-0.21	-0.41**	-0.39 **	0.09	0.11	-0.32**	1.00	
Tx	0.08	0.07	0.01	-0.01	0.02	0.10	0.05	-0.16	-0.01	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

Table 4. Pearson correlation matrix between the soil properties with 10m x 10m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.92**	1.00								
Exch K	-0.36	-0.27	1.00							
AZn	-0.21	-0.20	0.68**	1.00						
AFe	0.12	0.11	0.56*	0.72**	1.00					
AMn	-0.37	-0.16	0.36	0.30	-0.02	1.00				
AS	0.19	0.31	-0.06	0.38	0.15	0.35	1.00			
SOC	0.17	0.10	0.60*	0.61*	0.66**	0.00	0.25	1.00		
pH	-0.05	-0.06	-0.47	-0.44	-0.42	-0.06	0.06	-0.42	1.00	
Tx	-0.63*	-0.60*	0.48	0.21	0.12	-0.17	-0.27	0.20	-0.21	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

On the other hand, soil texture (Tx) has strong and negative correlation with available P (r=-0.63*) and total N (r=-0.60*). This means contents of available P and total N in soil increase with increasing fineness of soil. Data presented in Table 5 shows that available P has negative correlation with available Mn (r=-0.73*) and strong positive correlation with total N (r=0.95**) in soil. Macronutrient exchangeable K is strongly and positively correlated (r=0.91** to 0.95**) with micronutrients available Zn and Fe. Similarly, available Zn is positively correlated with available Fe (r=0.80*).

Table 5.Pearson correlation matrix between the soil properties with 15mx15m sampling density

	AP	TN	Exch K	AZn	AFe	AMn	AS	SOC	pH	Tx
AP	1.00									
TN	0.95**	1.00								
Exch K	-0.43	-0.38	1.00							
AZn	-0.47	-0.48	0.95**	1.00						
AFe	-0.54	-0.48	0.91**	0.80*	1.00					
AMn	-0.73*	-0.53	0.38	0.21	0.56	1.00				
AS	-0.08	-0.28	0.36	0.38	0.34	-0.11	1.00			
SOC	-0.58	-0.60	0.86**	0.81*	0.92**	0.39	0.37	1.00		
pH	0.49	0.50	-0.48	-0.50	-0.36	-0.21	-0.03	-0.56	1.00	
Tx	0.07	-0.05	0.33	0.49	0.25	-0.51	0.17	0.36	-0.37	1.00

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).
AP= Available phosphorus; TN= Total nitrogen; Exch K= Exchangeable Potasium; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; AS= Available Sulphur; OC=Organic Carbon; Tx= Soil texture (Sand/Clay).

Again, soil organic carbon (SOC) has significant positive correlation (r=0.81* to 0.92**) with exchangeable K, available Zn and available Fe in soil.

Geospatial variability of studied soil properties at various spatial resolutions

Spatial variations in the interpolated maps of soil properties

The interpolated maps of the studied soil attributes gave the visual representation of the study area on the differences of the physico-chemical status of the soil across the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m (Figure 2). Visual observation shows more patchiness in the interpolated surface map of soil texture in the higher resolutions (5 m × 5 m) compared to others (Figure 2). As indicated by the Tx value (Sand/Clay=7.2 to 10.0) of this map, greater portion of the land was medium textured soil. Other areas were either very coarse (Tx=10.0-21.0) or fine (Tx=3.2-7.2). In the least resolution or large scale (15 m × 15 m), the map showed that variance was not in spatially structured (one type of texture; the other type was not visible in the map due to the least number of data point in the classified data range) and the textural type was finer. Large and spatially gradient variability of the soil texture was found in the surface map of the unit land of which soil sampling was done in the medium scale (10 m × 10 m). In case of soil organic carbon, it was observed that the numbers of patches in the interpolated surface map of soil organic carbon (SOC) onto the land were much in the higher resolutions (5 m x 5m) compared to others. The heterogeneity of SOC of this resolution was much, where moderate status of OC (1.0-1.5%) was dominated. In the medium scale (10 m × 10 m), very prominent spatially gradient variability of the SOC exists with centering low status (<1.0%) and diverging higher status (1.0-1.5 and >1.5%) gradually towards the periphery along with nearly an equal share of areas. In the large scale (15 m × 15m) map, spatially gradient variability was also observed although it was not well-structured, where most of the areas were in the OC value of 1.0-1.5%. Patchiness in the interpolated surface map of soil pH onto the land was the higher in number in the higher resolutions (5m x 5m) compared to others.

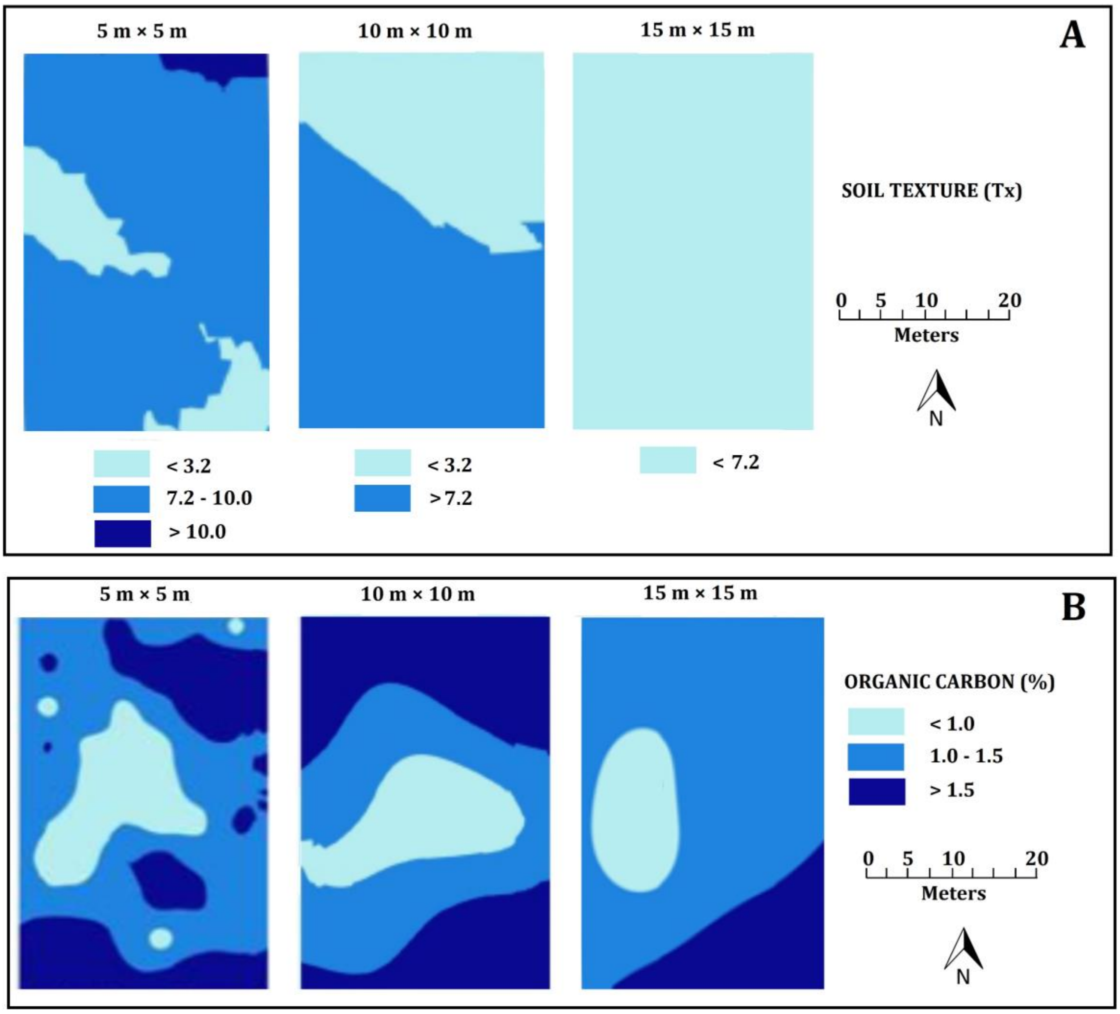

Fig.ure 2. Interpolated maps of soil texture (A), organic carbon (B), pH (C), available N (D), available P (E), available K (F), available S (G), available Fe (H), available Zn (I) and available Mn (J) obtained by ordinary kriging in the spatial resolutions of 5 m × 5 m, 10 m × 10 m and 15 m × 15 m (from left to right for each soil variable, respectively)

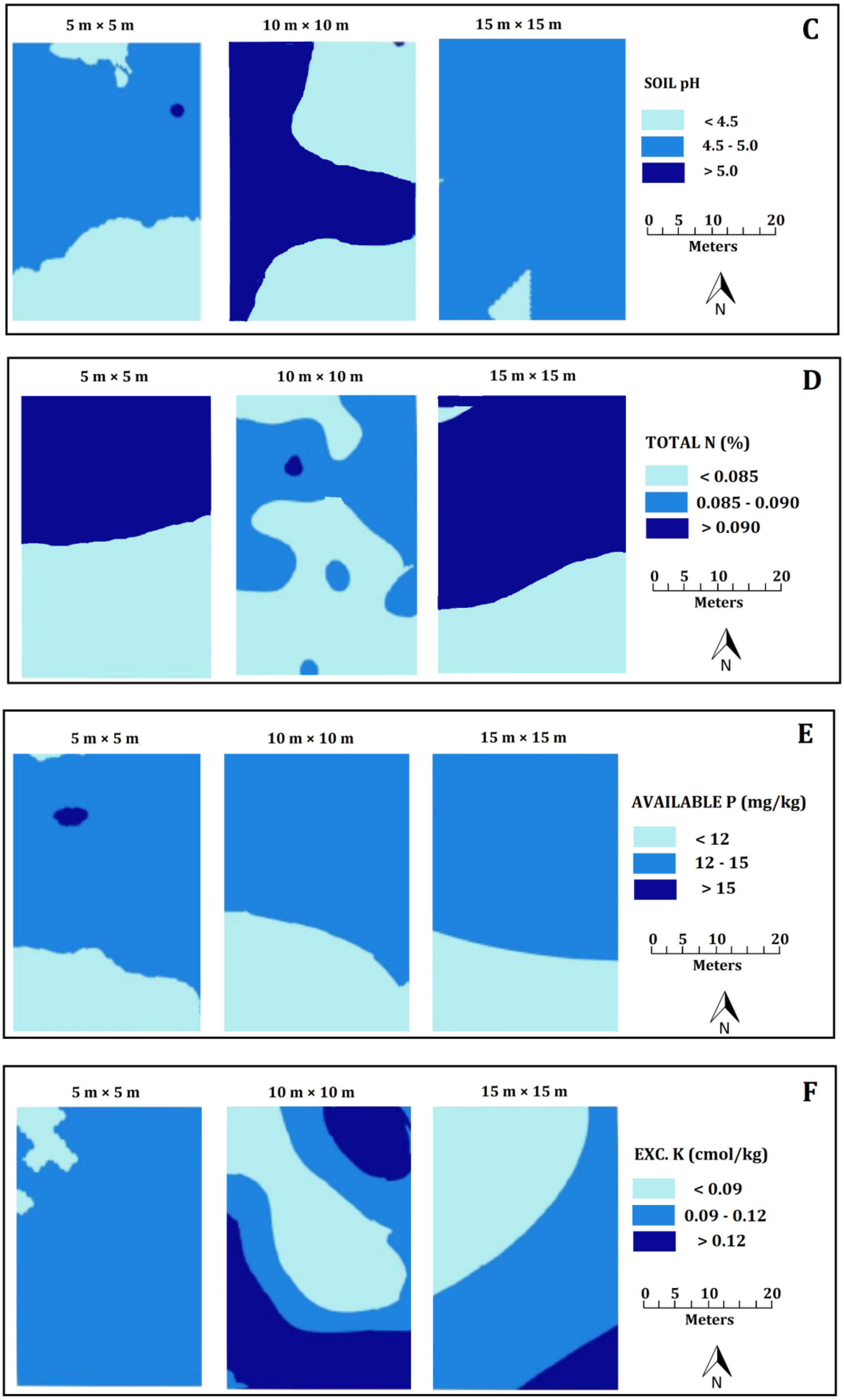

Fig.ure 2. (continued)

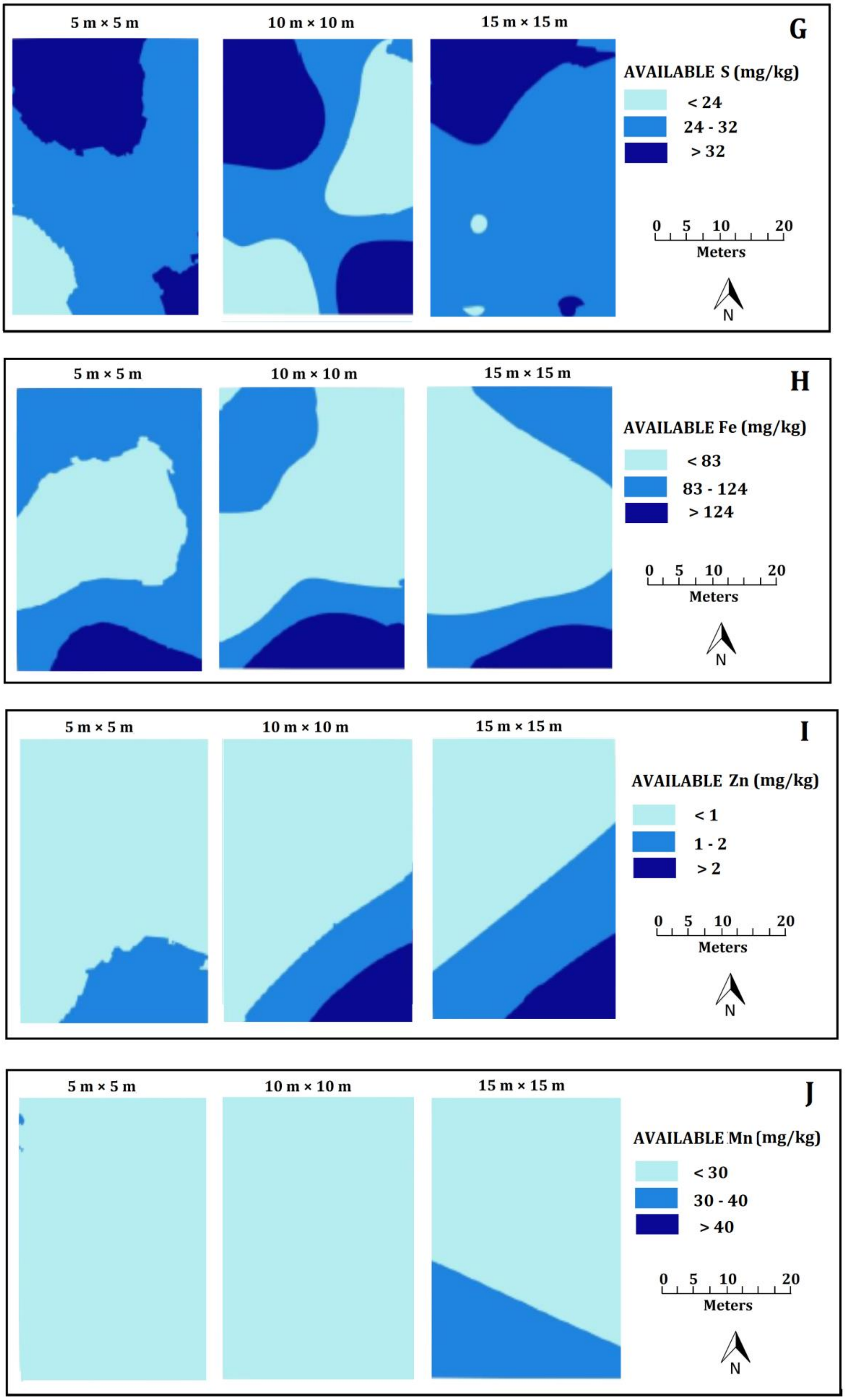

Fig.ure 2. (continued)

The greatest portion of the land was strongly acidic (pH=4.5-5.0) in reaction, considerable portion was very strongly acidic (pH=<4.5) and little portion is slightly acidic (pH>5.0) in this spatial resolution. In the medium scale (10mx10m), distinct spatially gradient variability of the soil pH exists (both strong and very strong reactions sharing almost equal areas) in the surface map of the land. In the large scale (15 m × 15 m), the map showed that variance was not distinct spatially structured where almost all areas were in the pH value of 4.5-5.0, and a small abrupt patch of very strong reaction was present at one side. It can also be noted here that in the latter scale, created surface map (by kriging) is not showing the legend color of one class (pH> 5.0) might be due to insufficient data point. Regarding total nitrogen, the patchiness in the interpolated surface map was higher in the moderate resolution (10 m × 10 m) while it was the least in high resolution (5 m × 5 m) and low resolution (15 m × 15 m). Spatially gradient structures were observed in the maps of all resolutions. In case of soil available phosphorus, the numbers of patches in the map were higher in the higher resolutions (5 m × 5 m) as compared to others. The spatial heterogeneity of AP of this resolution is more than others. Among the classified groups of AP, moderate status (12.0-15.0 mg/kg) prevailed in the major areas in the interpolated surface maps of all resolutions. The heterogeneity for AP gradually decreased with the decreasing the spatial resolution. In regards to exchangeable potassium, the patchiness (in terms of the number and areas of patches) onto the interpolated surface map was higher in the moderate resolution (10 m × 10 m) while it was the least in high resolution (5 m × 5 m).

Smooth spatially gradient structures were observed in both moderate and low resolution maps. The patchiness (in terms of the number and areas of patches) in the interpolated surface map of soil available S were higher in the moderate resolution (10 m × 10 m) while it was the least in low resolution (15 m × 15 m). Among the classes of AS in the maps, moderate one (24.0-32.0 mg/kg) appeared in the more areas in both low and high resolutions. In the moderate resolution, all three classes of AS (<24.0, 24.0-32.00 and >32.0 mg/kg) shared almost the same areas with smooth spatial gradient structure.

In regards to soil available Fe, spatially gradient structures were observed in the maps of all spatial resolutions (5 m × 5 m, 10 m × 10 m, 15 m × 15 m) of soil sampling. Among the classes of available Fe in the maps, moderate one (83.0-124.0 mg/kg) appeared in the more areas in both moderate and low resolutions. In the high resolution, two classes of available Fe (<83.0, and 83.0-124.0 mg/kg) shared almost the same areas centering the class with the lower value. Class of available Fe of >124 mg/kg covered the least areas in the maps of all resolutions. Regarding soil available Zn, the smooth and gradient spatial structures were pronounced in the maps of moderate (10 m × 10 m) and large (15 m × 15 m)-scale resolutions. The patchiness as well as the spatial heterogeneity was also higher in the surface maps of these two resolutions where low value class of Zn (<1.0 mg/kg) occupied major areas of the land in north-western side. In case of high resolution map, two classes of available Zn (<1.0, 1.0-2.0 mg/kg) covered the whole land of which low value class was dominated. In case of available Mn, the surface map showed that the variance of Mn in the high resolution (5 m × 5 m) was nearly non-spatially structured.

Similarly, the variance of Mn in the map of moderate resolution (10 m × 10 m) was perfectly non-spatially structured. Both maps showed only the lower value class of available Mn (<30.0 mg/kg) without displaying other legend colors due to insufficient data point of the concerned classes. In the large-scale resolution (15 m × 15 m), the spatially structured map was observed with two distinct classes of available Mn (<30 and 30-40 mg/kg).

Variations in the spatial autocorrelations of soil properties

The quantitative variations on the nature of spatial correlations (autocorrelation) for different soil attributes are shown in Table 6. The nugget effects as derived from the semivariograms of soil texture for the high (86%) and low resolutions (99%) indicate that soil texture has very weak autocorrelations (Table 6). Moderate spatial autocorrelation or spatial dependence of soil texture is found in case of moderate (10 m x 10 m) resolution (nugget effect: 45%). In case of all of the spatial resolutions, semivariogram of soil organic carbon gave very low to zero nugget effects (nugget/sill ratio: 0 to 7%) denoting very strong spatial autocorrelation or spatial dependence. Regarding soil pH, in the small–scale resolution (5 m × 5 m) a nugget effect of 9% denotes strong spatial autocorrelation, which is less than that of moderate spatial resolution (10 m × 10 m) (Table 6). A moderate spatial autocorrelation is found (nugget effect: 32%) in the medium-scale resolution (10 m × 10 m). On the other hand, in the large-scale resolution of soil sampling (15 m × 15 m), pure nugget effect (100%) is found meaning that there is no spatial autocorrelation or spatial dependence. For total nitrogen, in all resolutions, corresponding nugget effects of 39%, 37% and 60% indicate moderate spatial autocorrelation.

Table 6. Nugget effects as obtained from semivariogram during kriging in various spatial resolutions

Resolution		5 m x 5 m			10 m x 10 m			15 m x 15 m	
Soil Parameter	Model used	Nugget/Sill (%)	RMSE	Model used	Nugget/Sill (%)	RMSE	Model used	Nugget/Sill (%)	RMSE
Tx	Stable	0.99/1.12=86	3.659	Stable	0.25/0.55=45	1.883	Stable	2.82/2.85=99	2.093
Soil OC	Stable	0.0/2.40=0	0.409	J-bessel	0.18/2.31=7	0.343	J-bessel	0.1/2.59=3	0.273
Soil pH	J-bessel	0.1/1.078=9	0.324	J-bessel	0.21/0.65=32	0.243	Stable	1.4/1.4=100	0.407
Total N	Stable	0.55/1.4=39	0.003	Stable	0.85/2.27=37	0.004	Hole effect	1.5/2.5=60	0.005
AP	J-bessel	1.9/3.99=47	1.991	Stable	0.34/0.89=38	2.397	Pentaspherical	0.19/1.76=10	3.001
Exch K	Stable	1.24/1.24=100	0.035	Stable	0.04/1.2=3	0.025	Stable	1.0/3.36=30	0.043
AS	Stable	0.55/1.0=55	8.174	Stable	0.05/1.65=3	7.933	J-bessel	0.83/1.42=58	10.982
AFe	Stable	0.45/1.16=38	24.35	K-bessel	0/2.15=0	25.86	Hole effect	0.15/2.3=6	29.339
AZn	Stable	0.25/.509=49	0.552	Stable	0.3/2.21=13	0.978	Stable	1.03/5.13=20	1.460
AMn	Stable	0.45/0.75=60	8.153	Stable	2.49/2.50=99	5.641	Stable	0.75/1.95=38	11.491

Tx= Soil texture (Sand/Clay); OC=Organic Carbon; TN= Total nitrogen; AP= Available phosphorus; Exch K= Exchangeable Potassium; AS= Available Sulphur; AZn= Available Zinc; AFe= Available Iron; AMn= Available Manganese; RMSE= Root Mean Squired Errors.

In case of available phosphorus, the spatial dependence increased with the decrement of sampling density as observed by the nugget effects of 47%, 38% and 10%. In regards to exchangeable potassium, for the medium–scale resolution (10 m × 10 m), a nugget effect (nugget/sill ratio) of 3% indicates the strong spatial autocorrelation. Moderate spatial autocorrelation (nugget effect: 30%) is found in the large-scale resolutions (15 m × 15 m). On the contrary, in case of small-scale (5 m × 5 m) resolution, a little (or no) autocorrelation (nugget effect of 100%) is observed. For available sulphur, in the medium–scale resolution (10 m × 10 m) a nugget effect of 3% denotes the greater spatial autocorrelation. Moderate spatial autocorrelations are found in the both small-scale (5 m × 5 m) and large-scale resolutions (15 m × 15 m) as denoted by the nugget effects of 55% and 58%, respectively.

Regarding available iron, in the medium–scale (10 m x 10 m) and large-scale (15 m x 15 m) resolutions, corresponding nugget effects of 0% and 6% denote the greatest spatial autocorrelation (Table 6), which is also qualitatively observed in the interpolated maps (Figure 2). By observing the nugget effect of 38%, it can be said that moderate spatial autocorrelation or spatial dependence of available Fe occurred in the small-scale (5 m × 5 m) resolution. The nugget effects of available Zn for the medium (13%) and low resolutions (20%) indicate that Zn has strong spatial autocorrelations. Moderate spatial autocorrelation of available Zn is found in case of high (5 m × 5 m) resolution, where the nugget effect is 49%. Small–scale resolution (5 m × 5 m) and medium-scale resolution (10 m × 10 m) gave semivariograms from which calculated corresponding nugget effects of 60% and 99% reveal that available Mn has very weak spatial autocorrelation. On the contrary, large-scale resolution (15 m x 15 m) gave nugget effect of 38% denoting that it has moderate spatial dependence.

Discussion

Statistical variability of the studied soil attributes

Coefficients of variations (CVs) of TN, AP, AZn and AFe demonstrated a trend of increment across high-medium-low spatial resolutions. This variation was due to scalar variability of soil sampling to represent a unit land. Considering average CVs of all resolutions, variability of these nutrient elements ranked as AZn (mean CV=104.03%)>AFe (mean CV=41.67%)> AP (mean CV=20.32%)> TN (mean CV=4.92%) (Table 2). The CV of these soil elements might be associated with the mobility of the elements in soil. Mia (2015) reported that Zn, Fe and P are immobile in soil. Mobile nutrient element can homogenize across the land while immobile one cannot and gets possibility of having more CV. Contrary to the above soil attributes, no particular trend of increment or decrement of CV for soil texture, OC, pH, exch K, AS, and AMn was observed across the spatial resolutions. Again, considering mean CV of all resolutions, variability of these soil attributes ordered as exch K (mean CV = 35.17%)>AS (mean CV = 34.98%)>SOC (mean CV = 31.71%)>Tx (mean CV = 31.17%)>AMn (mean CV=30.10%)>Soil pH (mean CV = 6.96%). A study with a specific scale by Sharma and Sood (2020) reported that CV of soil fertility parameters was greater than 20%, and the CV of soil pH was 6.3%, which partially supports our results. The stated variability of soil attributes among them and across the spatial resolutions revealed the heterogeneity of soil within the plain land of 1500 m^2.

In case of all three resolutions, available P has strong and positive correlations with total N (r=0.94**, r=0.92** and r=0.95**) with varying strengths of correlation coefficients across the resolutions (Tables 3, 4, 5). Fageria and Oliveira (2014) reported a synergism of N and P contents in upland rice plant that could be a reflection of synergistic interaction of these two elements in soil. It is notable that soil pH has significant negative correlations with some other soil attributes like available Zn, available Fe and OC (r = -0.41**, r = - 0.39**and r = -0.32** respectively.) in case of only 5mx5m resolution, but not in case of other resolutions (Tables 3, 4, 5). This is due to scalar variability of soil sampling from the same unit of land. Lindsay (1979) reported that solubility of Zn and Fe increased tremendously due to decrement of soil pH value that supported the correlation of pH with Zn and Fe in our study. It is observed that the significant positive correlations exist between exchangeable K, available Zn in case of all three sampling densities (spatial resolutions) of the land, with varying and increased magnitude of the correlation coefficients across the resolutions (Tables 3, 4, 5) from high to low. Approximately zero-interaction between Zn and Fe in soybean as reported by Kobraee et al. (2011) differed our findings in regards to their availability in soil, might be due to their high solubility regulated by soil acidity in our strongly acidic study soil. Similarly, Exch K (r= 0.26*, r = 0.60* and r = 0.86**), available Zn (r = 0.37**, r = 0.61* and r = 0.81*) and Fe (r = 0.48**, r = 0.66** and r = 0.92**) have significant and positive correlations with SOC with varying and increased strength of coefficient of correlations across the spatial resolutions of sampling of high-medium-low. The density of sampling might be a cause of these variations of linear associations (r). The correlation with the mentioned mineral nutrients might be owing to the mineralization of soil organic matter. It is also noteworthy that soil texture (Tx) has strong and negative correlation with available P (r = -0.63*) and total N (r= -0.60*) in case of only moderate resolution (10 m × 10 m) but not in case of other resolutions due to differences of sampling densities and sample sizes devised for representing the same unit of land. The ability of fine textured (low value of Tx) soil to hold more nutrient elements and organic matter might be a cause of such negative correlation with available P and total N. The study reports of Zhou et al. (2019) for total N and of Niederberger et al. (2019) for P supported this correlation with soil texture.

Geospatial variability of the studied soil attributes

Spatially gradient well-structured to spatially gradient poor-structured interpolated maps were observed among the studied soil properties in the various spatial resolutions. These types of spatial variability were inconsistent in nature that is they did not follow a particular trend of variation across the soil attributes or across the resolutions. This proved the heterogeneity of soil even within a land of 1500 m^2. Similarly, spatial correlation spanned from very strong (nugget effect: 0%) to a little (nugget effect: 100%) across the soil attributes or across the spatial resolutions. With a particular scale and study area, Sharma and Sood (2020) found that spatial distribution maps of soil attributes relevant to fertility were not consistent and demonstrated strong to weak spatial autocorrelations for the soil parameters studied, which was in agreement with our findings.

Conclusion

The major soil properties in an acidic-level-fallow upland of around 1500 m^2 showed different variation in respect to statistical and geospatial variability across various resolution of soil sampling (5 m × 5 m, 10 m × 10 m, 15 m × 15 m). Depending on farmer's capacity and available facility, crops especially high valued ones (e.g. strawberry, dragon fruits, garden peas etc.) can be grown with site-specific nutrients or amendments applications based on the krigged maps generated from high resolution(s) soil sampling even in the small farmland as our study area. The revealed variability of soil properties would also help soil scientist or farm manager to make comparison of soil data/maps with proper consideration of spatial resolution of soil sampling. Such type of research should be confirmed by other similar studies preferably with high resolution with greater area. We could not study with higher resolution (high sampling density) due to error factor of GPS. Similarly we could not study with low sampling density (would result in insufficient data points) because of smaller size of the land (area of interest).

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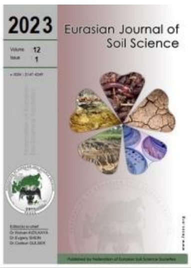

Assessment of land use land cover dynamics and its impact on springs water in Ritung Khola Sub-Watershed, Myagdi district, Nepal

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Abstract

Land Use Land Cover (LULC) Change has emerged as a significant environmental issue and a worry for the sustainable use of natural resources. This study was performed to determine the rate in change of land cover and its significant impact on springs water in the Ritung Khola sub-watershed of Myagdi district, Nepal, between 2010 and 2020. This study analyzes LULC dynamics and it's impact on springs water using satellite imageries (Landsat 5 TM and Landsat 8 OLI/TIRS) and focus group discussions with the inhabitants. We used Supervised Maximum Likelihood Classification algorithm to classify attributes of the LULC changes. The results demonstrated a significant change in LULC during those ten years (2010-2020). The area covered by agricultural land and human settlements significantly increased by 313.54% and 367.14%, respectively. On the contrary, barren land, water bodies and forest cover have been reduced by 37.52%, 13.16% and 5.26%, respectively. The number of active springs followed decreasing trend as many of them were completely displaced or dried due to erosions and frequent landslides. The findings from this study are expected to facilitate the planning process adopted to prevent springs under the threat of extension and mitigate the water scarcity problem.

Keywords: Landsat, land cover, land use, springs, watershed, water bodies.

Introduction

Land cover is defined as the physical and biological cover of the land surface, whereas land use means activities on physical things (such as agriculture, forest, building, and water) that tend to change the land surface phenomena (Mueller and Zeller, 2002; Foley et al., 2005). The unprecedented pace and magnitude of the anthropogenic activities on the land surface alter the Land Use and Land Cover (LULC) pattern, which is an absolute must to consider (Lambin et al., 2001; Zhang et al., 2015). LULC change is an endlessly changing phenomenon undergoing on the Earth (Reid et al., 2000).

In Nepal, several factors, including population growth, uneven economic development, and urban-centric economic growth, contributed to LULC dynamics (Rimal et al., 2018; Rimal et al., 2018b). These dynamics cause the environment to deteriorate and opened doors for major environmental dangers such as biodiversity loss, modifications to radioactive forcing and hydrological regimes, climate change, and contamination of other natural ecosystems (Niyogi et al., 2009; Liu et al., 2014; Porfiriev, 2015, Liping et al., 2018). Over the

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past few years, the forest area, water resources, and barren land have been changing and are likely to continue to change in the future (Dinka and Chaka, 2019).

Over the past few decades, remote sensing (RS) and Geographic Information System (GIS) become the prominent approaches for the understanding of spatiotemporal characteristics, and extraction of valuable information by classifying the spectral characteristics of land cover features for Natural Resource Management (NRM) (Jensen, 2005; Lillesand et al., 2015; Panigrahi et al., 2017). These techniques are useful for the management and improvement of the watershed by integrating and analyzing spatiotemporal data to study LULC changes at different levels (Attri et al., 2015). The image pixel was used as the basic unit of analysis in the 1980s and 1990s classification procedures, with each pixel being assigned to a certain land cover class. With progress, different classification techniques considering pixel as a basic analysis unit were developed, such as supervised (artificial neural network, decision tree, random forests, support vector machine, maximum likelihood classification), unsupervised (K-means and ISODATA), and hybrid classification (semi-supervised and mixing of supervised and unsupervised) techniques (Zhang et al., 2005; Alajlan et al., 2012).

The complex interactions between groundwater, surface water, and the aquatic-terrestrial ecotone are what make springs special and diverse (Von Fumetti et al., 2017). They are formed due to fractures, faults, and a rock contact form where groundwater emanates to the surface (Ibeneme et al., 2013). Globally, springs are considered 'natural laboratories' due to their peculiarity i.e. water reaches the surface through fracture of porous layer (Odum, 1971). They are extremely important to Nepal's rural areas, where about 80% of the country's 13 million residents who live in hills and mountains depend on them for drinking water (Tambe et al., 2012; Sharma et al., 2016; Bhat et al., 2020). The hydrology of the slope in Nepal's middle mountain has been disrupted by anthropogenic factors like as land cover changes, catchment degradation, and the construction of rural road networks (Ghimire et al., 2019). These activities result in the drying of springs and a reduction in the permanent flow of water from the springs during the dry season (ICIMOD, 2015; Chapagain et al., 2019; Ghimire et al., 2019). Although the springs play a significant role in water security, they haven't received adequate attention by protective legislation which in turn is leading to the threat of their drying up and the destruction of their natural habitat (Barguin and Scarsbrook, 2008; Cantonati et al., 2012).

LULC changes also have notable impacts on the quality and quantity of several forms of water such as groundwater, surface runoff, and the dissemination of non-point source (NPS) pollutants over a range of spatiotemporal scales (Weng, 2001; Frumkin, 2002; Li and Wang, 2009). The springs in the Ritung Khola sub-watershed are facing several threats and are on the verge of disappearance. Furthermore, the evaluation of LULC dynamics in this sub-watershed with the combined tools of RS, GIS, and the social study has not been practiced in this sub-watershed until the date. This sub-watershed is one of those notable examples where no information available regarding LULC changes, even though it mixes with the Myagdi River (perennial river originated from Mt. Dhaulagiri).

This study was carried out with a general goal to understand the dynamics of LULC between 2010 and 2020 and their impact on springs water availability. In addition, the specific objectives of our study were

i. to assess the effectiveness of historical Landsat images for detecting LULC changes over the ten years (2010-2020),
ii. integrating the remote sensing techniques with local people's perception regarding the changes, and
iii. creating a detailed LULC change map of the Ritung-Khola sub-watershed area at a spatial resolution of 30 m.

The long-term study of the change in the land cover and its linkages with the underground water availability bolsters the efficient use and preservation strategies of these water sources in most of the hilly landscapes. Temporal information of land coverage and its conservation is an asset for the sustainable development of a community. There have been several related studies on land cover changes previously; however, researchers have failed to analyze the linkage between LULC and Ground water resources. Ritung Khola sub-watershed is a representative sub-watershed for the entire Hindu Kush Himalayan (HKH) region and the associated community. Entire HKHs region is facing water resources depletion over few decades due to different environmental and climatic changes. In this context, this study emphasizes the importance of temporal change in land phenomena and its impact on springs resources.

Material and Methods

Study area

This study was performed in the Ritung Khola sub-watershed area ($83^0$18'0" E to $83^0$24'0"E and $28^0$21'0"N to $28^0$27'0"N) of the Malika Rural Municipality, Myagdi district, Gandaki Province, Nepal (Figure 1). The sub-watershed encompasses a 71.44 km^2 area. The outlet of this sub-watershed drains into the Myagdi River through the Ritung River (Ritung Khola), which is also a tributary of the Kali Gandaki River. The two main branches of the Ritung River are the Dajung River and the Ruma River (Khahare Khola). The altitude of the study area ranges from 1,076 m (confluence of Myagdi River and Ritung River) to 3,470 m (Sarbara danda) (Figure 1). There exist three types of climatic conditions in this sub-watershed: subtropical, temperate, and subalpine. This sub-watershed is more facing towards the north east rather than south west. This sub-watershed is more prone to soil erosion bearing the land capability class III and class IV within most of the sub-watershed (LRMP, 1986). Indian dammer (*Shorea robusta*), chestnut (*Castanopsis indica*), Indian or Nepalese alder (*Alnus nepalensis*), pine (*Pinus* sp.), and Chinese guger tree (*Schima wallichii*) are the major tree species found in this area. The land use pattern of this study area was found well managed to the date as majority of the settlements are around the cultivable land, mostly along with spurs and saddles. However, the migration of people from uplands towards the low land for facilities and other benefits is resulting in the unsustainability of the land-use system. The settlement area covers about 30% of the total area of the watershed. Therefore, to disseminate the information for the management of land-use system and conservation of springs in the sub-watershed, selection of this area for our study was vital.

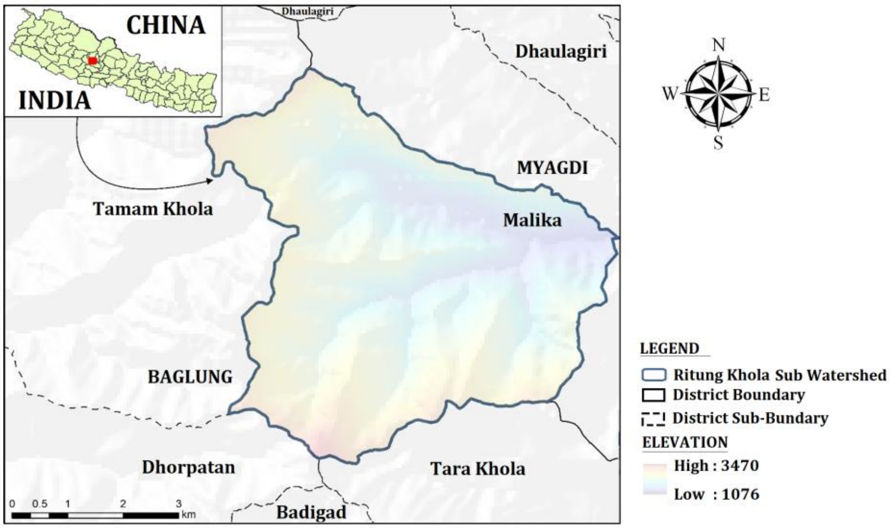


Figure 1. Study area map showing Ritung Khola Sub-watershed area

Data collection

Field data

Primary data like information from Focus Group Discussions (FGDs) were used to identify springs conservation activities, use status and perception, GPS point for training sample and accuracy assessment. Secondary data like Landsat images were used for image classification and to determine LULC change, and other literature to acquire knowledge about methods and analysis techniques. Fieldwork was started with a reconnaissance survey which was conducted in April 2021 to obtain a general understanding of the LULC status of the study area. During this survey, ground information was acquired to define the nature of ground covers such as forests, agriculture, water bodies, barren land, and settlements. A reconnaissance survey was followed by the primary data collection. The field data were collected from random locations and 338 GPS points for 2020 image classification were obtained covering all the LULC classes during fieldwork in April 2021. The history of each types of land use was acquired from the local people by the means of FGDs. FGDs were also utilized to collect other additional data from the respondents to determine the impacts of each LULC class on the springs water of the study area.

Satellite data acquisition

The watershed boundary was delineated using the Shutter Radar Topography Map (SRTM), Digital Elevation Model (DEM), and atmospherically corrected Landsat data which were downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). Landsat data included surface reflectance bands in Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) images (Table 1).

Table 1. Characteristics of the satellite images used in this study

Satellite	Sensor	Spatial resolution (m)	Path/Row	Date of acquisition
Landsat 5	TM	30	142/40	2010/12/03
Landsat 8	OLI/TIRS	30	142/40	2020/11/12

LULC classification

The steps involve in supervised image classification were:

Defining training sites

A total of 338 training points (agriculture 60, settlements 51, water bodies 74, barren land 71, and forest 82) for image classification for 2020 image were identified, and for 2010, 492 training points (agriculture 145, settlements 55, water bodies 61, barren land 87, and forest 144) were taken.

Image classification

The supervised classification technique was carried out to classify the pre-processed Landsat images from the individual dates. Maximum Likelihood Classification (MLC), one of many supervised classifiers, was regarded as a widely used method for categorizing the pre-processed satellite image (Lillesand et al., 2015; Yang et al., 2015). It automatically classifies pixels in an image into a target class (Vahtmae et al., 2012). The LULC classification scheme is shown in (Table 2). Images that have the same spectral signature such as natural and plantation forests, riverine forests, and dry evergreen forests were included in the class forest because of the difficulty in differentiating one from the other.

Table 2. Characteristics of the LULC classes used in the study.

Class name	Description
Forest	Trees forming closed or nearly closed canopies; natural, plantation, and degraded forest, shrubs, and herbs.
Agriculture	Crop and fallow lands.
Barren land	Exposed soil, barren area, exposed rocks, and permanently abandoned land.
Water bodies	Rivers, open water, streams, ponds, and reservoirs.
Settlement	Residential, commercial, industrial, urban, and rural settlements.

Focus Group Discussions (FGDs)

Three Focus Group Discussions (FGDs) involving a total of 31 participants were conducted to better understand the dynamics of LULC and its effect on springs water. Each group consisted of 12, 9 and 10 members from the three selected localities in the study area (Phulbaari, Aadhibara, and Okharbot), respectively. The age of participants involving in discussion ranged from 30 to 75 years. A local motivator with strong understanding of the surrounding areas helped to identify the participants. The trained facilitator of each focus group led the participants through a set of pre-planned questions. The drivers of spring water depletion due to LULC change in this study area were identified, classified, and ranked after identifying the main issue of spring depletion based on the outcomes of consultation with the respondents. Scores for identified causes and drivers were assigned using pairwise ranking (Bekele et al., 2018). The discussion questions were open-ended and designed mainly to identify the impact of LULC changes on spring water according to the perceptions of the locals. In each group meeting, questions related to the impacts of LULC on springs water, conservation measures of springs, and government, Non-governmental Organizations (NGOs), International non-governmental organizations (INGOs), and Community-based Organizations (CBOs) support for the springs' conservation were asked. Each meeting lasted for approximately an hour, and the text contains the responses. Data from field observations of LULC change and spring water were also gathered by the research team and used in group discussions, problem explanations, and result interpretations.

Data analysis

Accuracy assessment for LULC classification models

We assessed the accuracy of our LULC classification models using the simple random sampling method (Li et al., 2021). The random points were adopted to validate the classification accuracy of LULC data in Google Earth Pro. For the referenced or sample database, this study used Google Earth Pro and ground verification points from different places lie in this sub-watershed. A total of 338 training samples were used to classify an image of 2020 and those samples were checked in Google Earth Pro for validation or accuracy assessment. A historical Google Earth image was used as reference data for the accuracy assessment of the 2010 image. The distance between random points was assigned a minimum of 30m and a maximum of 50m distance apart. A total of 338 and 492 training samples were collected based on the visual abundance to prepare the LULC map of 2020 and 2010 respectively. For the validation, 97 and 153 points were used for the years 2020 and 2010 respectively, where more validation points were used for the year 2010 to ensure better classification based on old imageries. After that, the created ground truth points were superimposed on the LULC map, and the value was extracted. The KAPPA test, which is based on a confusion matrix after the classification, was used to compare the referenced data and the classified image statistically. Lastly, the accuracy of the classified images was calculated based on the calculation of users, producers, and overall accuracy. Formulae for overall accuracy, user's accuracy, and producer's accuracy which are used for accuracy assessment are:

$$\text{Overall accuracy (\%)} = \frac{\text{Total number of correctly classified pixels (Diagonal)}}{\text{Total number of referenced pixels}} \quad (1)$$ (Bharatkar and Patel, 2013)

$$\text{User's accuracy (\%)} = \frac{\text{No. of correctly classified pixels in each category} * 100}{\text{Classified total pixels in that category (Row total)}} \quad (2)$$ (Bharatkar and Patel, 2013)

$$\text{Producer's accuracy (\%)} = \frac{\text{No. of correctly classified pixels in each category} * 100}{\text{classified total pixels in that category (Column total)}} \quad (3)$$ (Bharatkar and Patel, 2013)

Another method of accuracy assessment is KAPPA which still makes use of the error matrix (Congalton, 2001). Its value ranges from 0 to 1 where 0.80 signify a strong agreement, 0.40-0.80 denote a moderate agreement, and below 0.40 characterize a poor agreement (Congalton, 1996). This study follows the equation (4) given by (Foody, 2002; Rwanga and Ndambuki, 2017) for KAPPA statistics calculation in accuracy assessment.

$$\text{KAPPA (K)} = \frac{\mathrm{N}\ \sum_{i=1}^{r} x_{ij} - \sum_{i=1}^{r}(x_{i} * x_{+i})}{\mathrm{N}^2 - \sum_{i=1}^{r}(x_{i+} * x_{+i})} \quad (4)$$

Change detection

The rate of change ha/year and percentage share of each class during the studied periods were calculated using the formula given by (Shiferaw and Singh, 2011).

$$\Delta\mathrm{A}(\%) = \frac{(\mathrm{At2} - \mathrm{At1}) * 100}{\mathrm{At1}} \quad (5)$$

where, Δ A (%) = percentage change in the area of LULC class type between initial time At_1 and final period At_2, At_1 = area of LULC class at an initial time, At_2= area of LULC class at the final time.

Results

LULC status of Ritung Khola sub-watershed in 2010

A total of five LULC classes namely, Forest, Agriculture, Water bodies, Settlements, and Barren land were used for the classification purposes (Table 2). Forest constituted the highest area (5963.56 ha, 83.48%) from the study site, followed by the Barren land (948.60 ha, 13.28%). Agriculture land, Water bodies, and Settlements covered an area of 205.66 ha (2.88%), 18.93 ha (0.27%), and 7.36 ha (0.09%) respectively (Table 3, Figure 2a).

Table 3. Area and percentage coverage of LULC of Ritung Khola sub-watershed in 2010

Year: 2010		
Land classes	Area (ha)	Area coverage (%)
Forest	5963.56	83.48
Agriculture	205.66	2.88
Water Bodies	18.93	0.27
Settlements	7.36	0.09
Barren Land	948.60	13.28
Total	7144.12	100

LULC status of Ritung Khola sub-watershed in 2020

Various changes were observed for the same land cover classes in a 10-years interval. The post-classification of the Landsat image of 2020 showed forest covering an area of 5650.10 ha (79.09%) of the total study area. Agriculture land had occupied an area of 851.94 ha (11.92%) of the study area. The barren land, settlement, and water body had covered an area of 592.89 ha (8.30%), 32.7 ha (0.46%), and 16.49 ha (0.23%) respectively (Table 4, Figure 2b).

Table 4. Area and percentage coverage of LULC of Ritung Khola sub-watershed in 2020

Year: 2020		
Land classes	Area (ha)	Area coverage (%)
Forest	5650.10	79.09
Agriculture	851.94	11.92
Water Bodies	16.49	0.23
Settlements	32.70	0.46
Barren Land	592.89	8.30
Total	7144.12	100

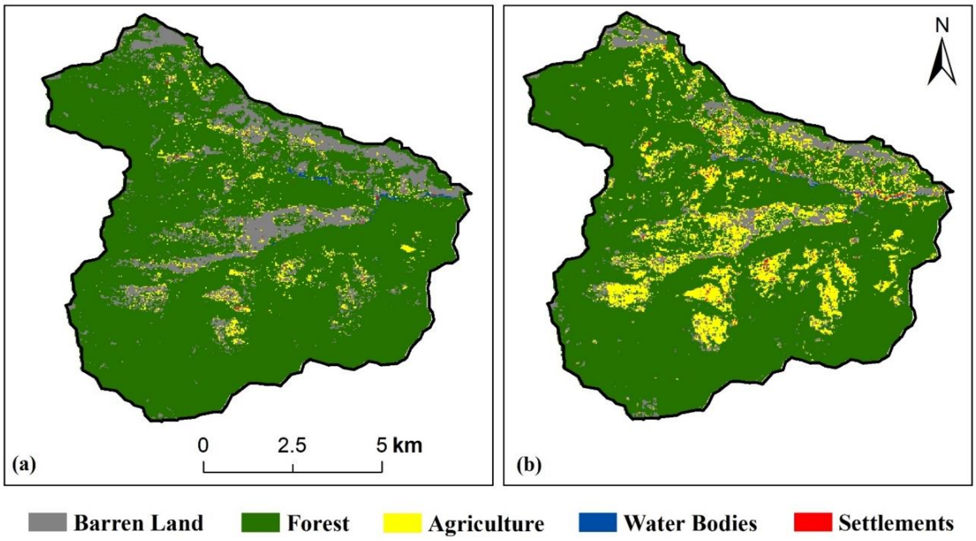


Figure 2. (a) Land Use Land Cover Map of Ritung Khola Sub-watershed- 2010 (b) Land Use Land Cover Map of Ritung Khola Sub-watershed- 2020

Accuracy assessment of LULC classification

The overall accuracy and Kappa coefficient of the classified images were 86.4%, and 0.81 for 2010 and 85%, 0.82 for the 2010 respectively.

Land use and land cover class change trends between 2010 and 2020

The change in area of LULC types during the period (2010-2020) in the Ritung Khola sub-watershed are demonstrated in (Table 5). During 10 years, the area covered by Settlements class in this sub-watershed surged by more than 300%, i.e., 0.09% to 0.46% representing a 25.7 ha increases in area. The agriculture class also increased by 313.54%, i.e., 2.88% to 11.92% (645.9 ha increase in the area). The barren land decreased from 13.28% to 8.30% (decrease in the area of 356.1 ha). Between 2010 and 2020, there has also been a reduction in the area occupied by water bodies. The percentage decrease in the class of water bodies was 13.16% that is 0.27% from 2010 to 0.23% in 2020 with a decrease in the area of 2.5 ha. The classification result showed that the forest land decreased over the last 10 years by 5.26% i.e., 83.48% from 2010 to 79.09% in 2020 with a decrease in the area of 314 ha.

Table 5. Composite table of area statistics (ha and %) of Ritung Khola sub-watershed in 2010 and 2020

S.N.	Land Cover Classes	Total change in status between 2010-2020	
		Area (ha)	Coverage (%) change between 2010 and 2020
1.	Forest	-314	-5.26
2.	Agriculture	645.9	313.54
3.	Water Bodies	-2.5	-13.16
4.	Settlements	25.7	367.14
5.	Barren Land	-356.1	-37.52

Land use land cover change transition matrix from 2010-2020

A total of 1358.443 ha of land area were transitioned from one class to another class in this study period. During the time interval, major changes could be observed in the class agriculture i.e., 646.28 ha. Considering the 205.657 ha area that was agricultural area in 2010, 114.868 ha were still agricultural land, but approximately 90.789 ha of agricultural land was converted to other land cover classes (65.545 ha to forest, 0.805 ha to water bodies, 4.874 ha to settlements, and 9.565 ha to barren land). Similarly, barren land area experienced a conversion of 608.398 ha (252.225 ha to forest, 343.709 ha to agriculture, 2.104 ha to water bodies, and 10.36 ha to settlements) but it retained 340.207 ha in 2020 as barren land. Furthermore, the forest land retained 5327.144 ha of it in 2020 with an overall transition of 636.42 ha (387.118 ha to agriculture, 10.575 ha to water bodies, 16.473 ha to settlements, and 222.254 ha to barren land). In addition, the area of the settlements changed by 6.904 ha (2.161 ha to forest, 3.555 ha to agriculture, 0.005 ha to water bodies, and 1.183 ha to barren land). The least change was observed in water bodies as out of 18.934 ha area in 2010, 3.002 ha was still water bodies in 2020, but about 15.932 ha of water bodies area was converted to other classes (3.029 ha to forest, 2.687 ha to agriculture, 0.531 ha to settlements, and 9.685 ha to barren land) (Table 6). The water bodies were mainly replaced by barren land followed by forests and agricultural land. The modifications that took place in each class are listed in (Table 7).

Table 6. The cross-tabulation matrix of land cover classes between 2010 and 2020 (Area in ha)

Land Use Land Cover Classes		2020					
		Forest	Agriculture	Water Bodies	Settlements	Barren Land	Total (2010)
2010	Forest	5327.144	387.118	10.575	16.473	222.254	5963.564
	Agriculture	65.545	114.868	0.805	4.874	19.565	205.657
	Water Bodies	3.029	2.687	3.002	0.531	9.685	18.934
	Settlements	2.161	3.555	0.005	0.459	1.183	7.363
	Barren Land	252.225	343.709	2.104	10.36	340.207	948.605
	Total (2020)	5650.104	851.937	16.491	32.697	592.894	7144.12

Table 7. Summary of land cover conversion between 2010 and 2020

Land cover classes	Total land area converted (ha)
Forest	636.42
Agriculture	90.789
Water Bodies	15.932
Settlements	6.904
Barren Land	608.398
Total	1358.443

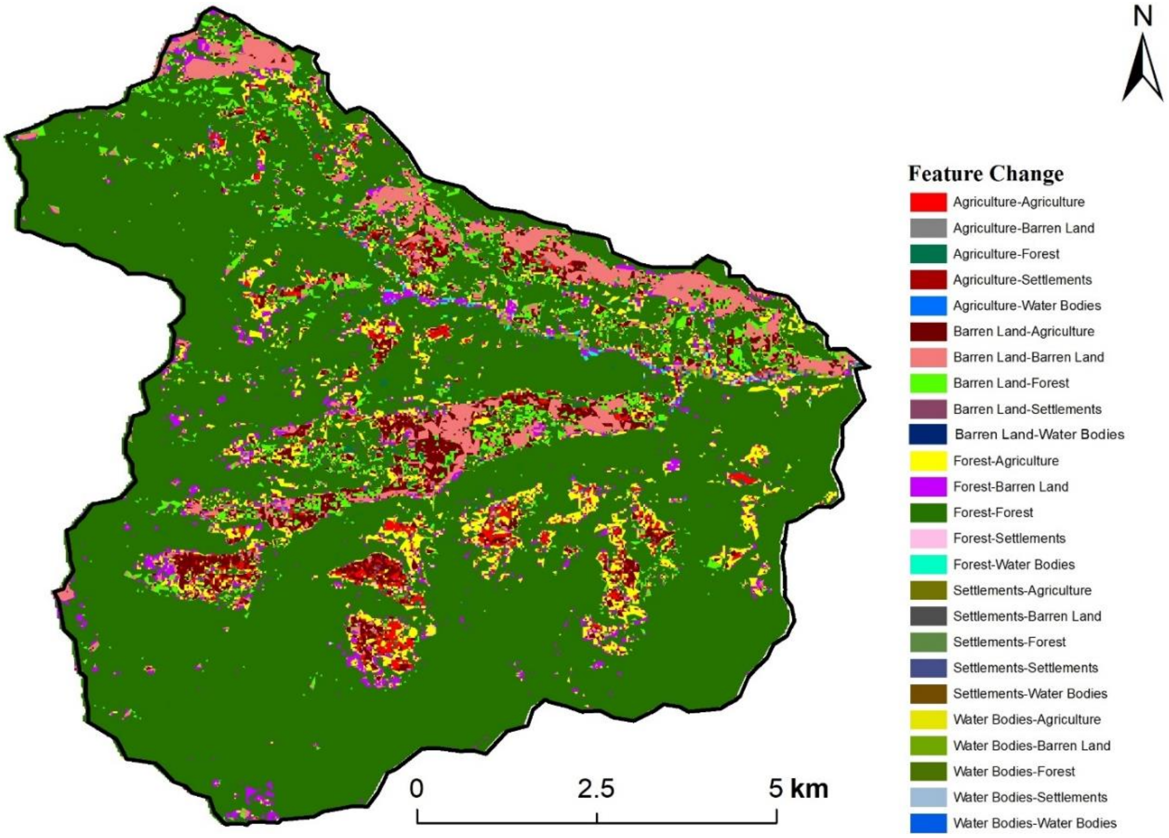


Figure 3. LULC class changes between 2010 and 2020

Impacts of LULC dynamics in springs in Ritung Khola sub-watershed

Among three FGDs, the discussion carried out in Malika Rural Municipality-04, Phulbari, Myagdi with local participants revealed that there were around four springs in the "Datreni'' area in 2010 but now, hardly 1-2 springs are seen in this area. There were no activities or programs from the government bodies, NGOs, INGOs, and CBOs for the conservation of springs in that area. However, the application of bio-engineering techniques (plantation of *Bambusa* sp., *Bauhinia variegata*, and *Ficus semicordata*) is currently implemented by the locals to protect the land from erosion and landslide which somehow conserves the displacement of existing springs.

Another discussion was carried out in Malika Rural Municipality-03, Aadhibara, Myagdi which indicated that the constructions of roads (five roads in Niskot currently under construction), agricultural land transformation into barren land, Bilbang landslide, and decrease in forest cover by 3-4% in the last 10 years are the key factors for decreased springs in this area. There were six springs in 2010 but tentatively around 2 springs are currently functional. Similarly, the discussion carried out in Malika Rural Municipality-04, Okharbot, Myagdi, disclosed that the construction of roads is the major parameter to lessen springs. Recently, there are around 25 springs, but only one is used by them. The spring name “Dadagaun Mul” was used by the people of Okharbot for irrigation, drinking, and several household purposes. There exists another spring “Tamakhani Mul” but the people don’t use water from this spring. The water from ‘Dipli Khola’ is used by the people for drinking purposes. Dhordore kholso and Asare kholso consist number of springs in past but nowadays its availability is in decreasing trend. The surface runoff that occurs from the Okharbot in a sloppy land brings a landslide that has direct impacts on the nearby village ‘Jukepani Tole’ in the lower area. But recently, engineering techniques have been implemented using gabions to control the landslide and help protect the life and settlements of the “Jukepani Tole”. We observed four springs where water level has decreased year by year (Figure 4).

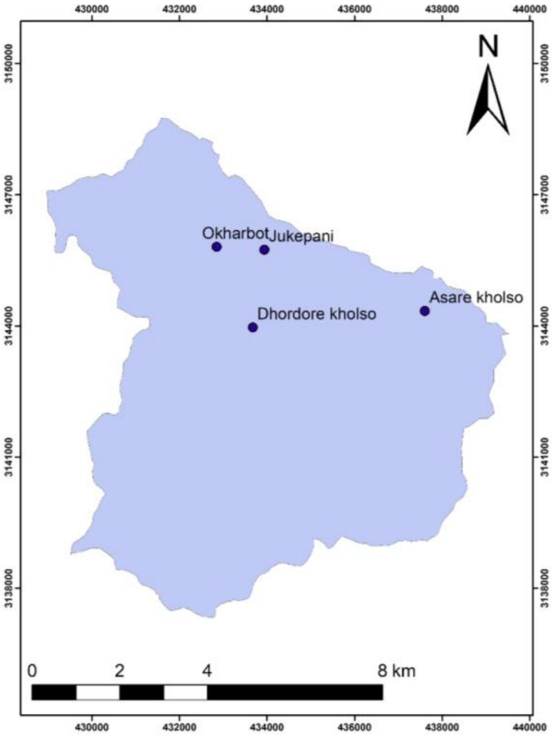


Figure 4. Springs which were active but has decreased water availability

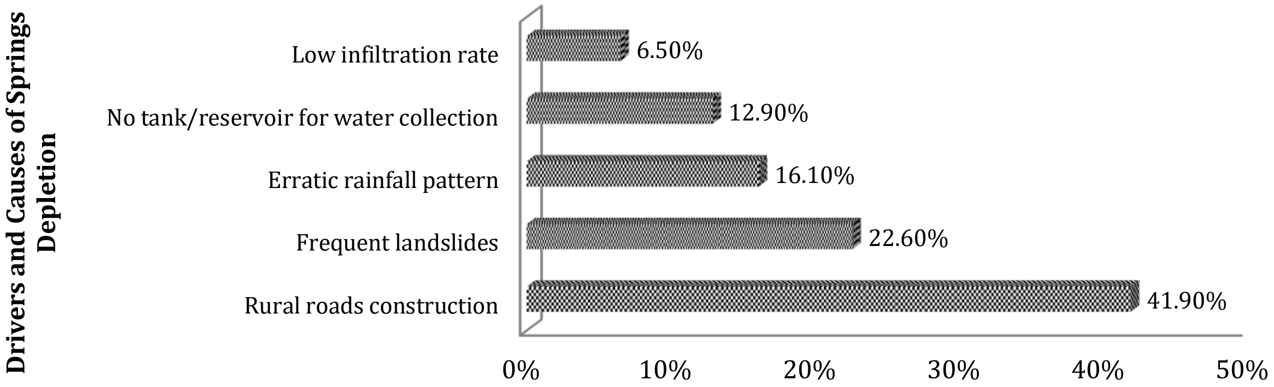
After finalizing the discussion in three selected areas, the main reasons behind the depletion of springs were ranked according to the perceptions of the local people. Rural roads construction was ranked first (41.9%) according to the FGDs (Table 8). Then the frequent landslide was ranked second (22.58%), due to the haphazard road construction. Erratic rainfall pattern ranked third (16.13%), no tank/reservoir for water collection ranked fourth (12.9%), and finally, low infiltration rate ranked fifth (6.45%), and this is solely due to the following reason (Table 8, Figure 5). The priority-based ranking table of causes and drivers of springs depletion is shown in Table 8.

Table 8. Priority ranking table of causes and drivers of springs depletion

S.N.	Drivers of Springs depletion	Score	Rank
1.	Frequent landslides	7	2
2.	Low infiltration rate	2	5
3.	Rural roads construction	13	1
4.	No tank/reservoir for water collection	4	4
5.	Erratic rainfall pattern	5	3

The main drivers or causes of springs depletion revealed and ranked during the discussions due to LULC change are presented in (Figure 5).

In a nutshell, the group discussion carried out in three areas of this sub-watershed comparatively summarized that the springs are in decreasing trend due to several drivers which are aforementioned. They further elaborated on the impacts perceived by springs as a result of these drivers in this sub-watershed, which is clearly shown in (Figure 6).



	Rural roads construction	Frequent landslides	Erratic rainfall pattern	No tank/reservoir for water collection	Low infiltration rate
▨ Score (%)	41.90%	22.60%	16.10%	12.90%	6.50%

Figure 5. Rank of main drivers and causes for springs depletion by local people

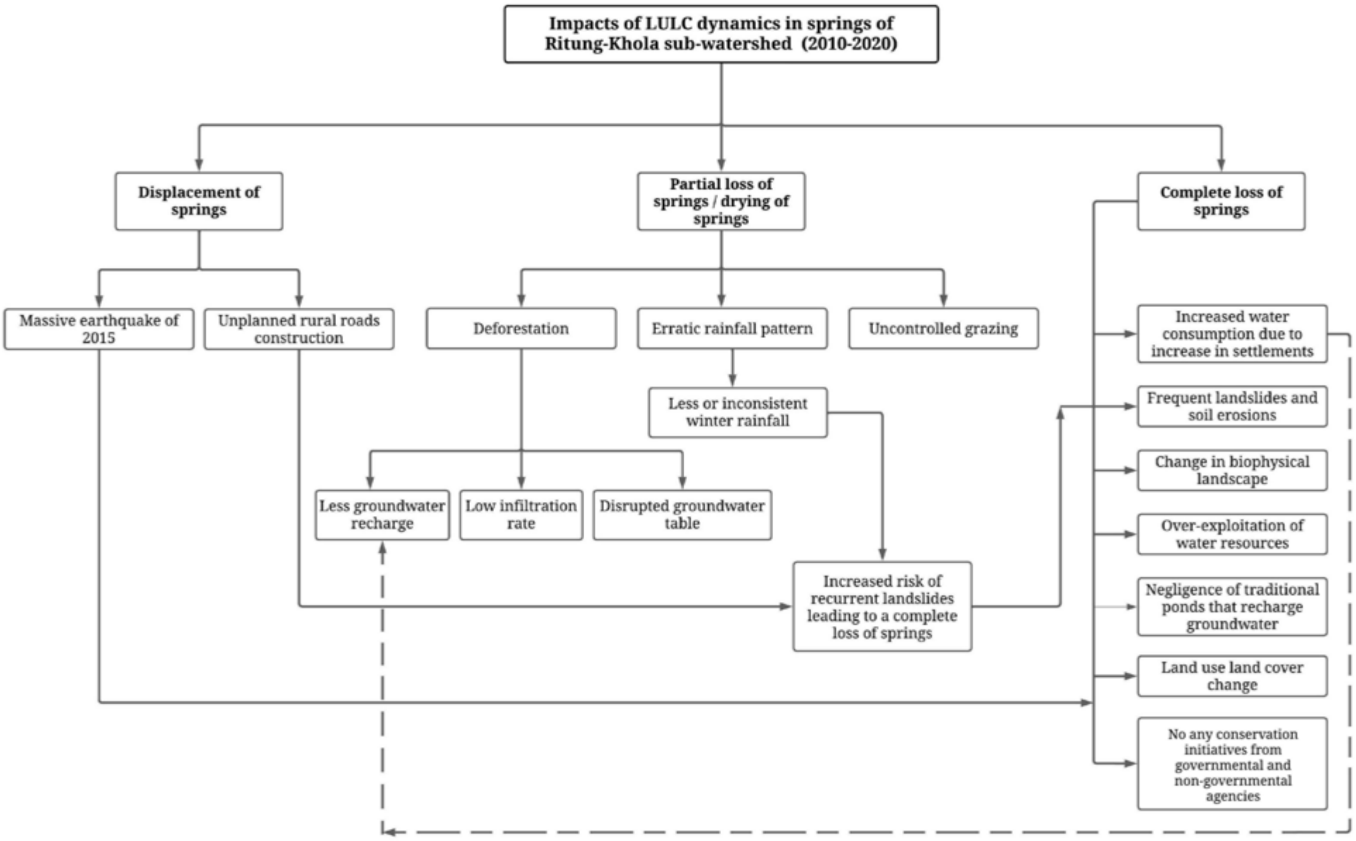


Figure 6. Flow chart showing the impact of LULC changes in springs as per the responses from the locals.

Discussion

Land Use Land Cover status of Ritung Khola Sub-watershed

Detecting changes and classifying LULC have been made easier by integrating GIS and RS data (Lo and Yeung, 2007; Dengiz, 2018). The multi-temporal Landsat series of imageries were used for the LULC classification in our study as performed in several other research (Yuan et al., 2005; Lu and Weng, 2005). However, there are several limitations of this method during image classification (Rogan and Chen, 2004) as it could have challenges with the heterogeneity of the environment which was problem during our study as well (Herold et al., 2002; Baghdadi and Zribi, 2016). The sporadic and unplanned patches in this sub-watershed area also pose a challenge for accuracy (Abdullah et al., 2019; Cai et al., 2019). Despite the fact that RS techniques have significant drawbacks, they have a number of advantages over conventional methods in terms of repeating coverage, inexpensive data capture, and extensive coverage (Xie et al., 2008; Kadhim et al., 2016). MLC algorithm was used for the LULC classification and determine their changes over the time and space (Norovsuren et al., 2019; Tripathi et al., 2020; Rakhmonov et al., 2021; Regasa et al., 2021).

Initially, land use classification map for 2010 showed that agriculture land is distributed between the dense forest area and the banks of rivers (Figure 2a). Most of the agriculture lands were fallow as the population was low. The reverse was found in the year 2020 when fallow lands were used up for agriculture and settlements substantially increased (Figure 2b). The analysis of the LULC from 2010 and 2020 reveals that this sub-watershed shows a magnificent transition from one land cover to another (Table 6). The increasing trend in LULC change directs the influence of population change and economic development in the sub-watershed (Attri et al., 2015). The change map also demonstrates that the agricultural land and settlements are in increasing trend whereas, forest, barren land, and water bodies are in the decreasing trend during these 10 years (Figure 3). The reason for declining forest cover might be due to the expansion of rural roads network, dependency of locals on forests for fuelwoods, cattle grazing, and deforestation (Thapa and Weber, 1995; Tiwari, 2000). The discussion conducted in Aadhibara reveals that forest cover decreased by 3-4% over the past 10 years. The results show that most of the forest area has been converted to agricultural land (Kandel et al., 2010). A study of Soussan et al. (1995) showed a comparable result with our study stating that rural road networks and infrastructure development has resulted in the clearing of forest cover in the hills of Nepal. Chaudhary et al. (2016) also found infrastructural development as a main cause of forest cover removal in Nepal. However, there is a little bit of depth in our result on how barren land and forest land both get decreased (Table 5). Barren land can decrease due to several efforts such as afforestation programs or could be replaced by agricultural land which is evident in our study (Table 6). The positive side is the lowest percentage change in forest cover (5.26%) as compared to other land classes where the decrease is attributed to some artificial interventions and construction of roads and foot trails in this sub-watershed.

A significant portion of forest-land was converted to other LULC categories, primarily to barren land, and agricultural land (Baral et al., 2018). According to the FGDs, most of the forest area has been cleared by encroachment for agriculture or construction purposes i.e., barren land for the construction of settlements. There is no introduction of a community forest program for the conservation of forest resources, which is also the main reason for the decline in forest cover which is contrary with the finding of Choudhary and Pathak (2016). Agricultural land has gone up from 2.88% (205.66 ha) in 2010 to 11.92% (851.94 ha) in 2020 with a significant increase in the area (645.9 ha), i.e., more than threefold increase in coverage (Table 5). Encroachments of other land covers including uncultivated areas of forest land results in agricultural expansion (Bufebo and Elias, 2021). Previously, the people residing in this sub-watershed mainly grew crops on steep slopes but nowadays, production and expansion of cropland extend to the peripheral land (around settlements and roads too) due to increase in population (Choudhary and Pathak, 2016). The use of different modern agricultural technologies and easy availability of labor (both men and women) are the factors in increasing agricultural land (Maharjan et al., 2020). Agricultural land was also increased at the expense of barren land and forests (Dhakal, 2010; Chalise and Kumar, 2020). The majority of people in FGDs was farmers and engaged in farming activities to run their livelihood. Paudel et al. (2016) mentioned that the farmland has increased by 13% around the nation over the recent 50 years which signifies the finding of this study. The main tenets of expanding agricultural land throughout the nation after the 1990s are the long-term plan and policies (Pesticide Act 199, Agriculture Perspective Plan 1995/96, and Land use policy 2012) and the development of infrastructure across the nation (MoAD, 2015). CBS (2019) indicated that 93.7% of agricultural land in 2011 was obtained from land-use statistics for Nepal. Similarly, barren land has decreased from 13.28% (948.60 ha) to 8.30% (592.89 ha) during this period. Most of the barren land is converted into agricultural land which is the main reason for increasing agricultural land and decreasing barren land (Koirala, 2010). Some researchers (Adhikari et al., 2018; Chalise and Kumar, 2020) summarized that there was a decrease in percentage of barren land from 1995 to 2015 and 1993 to 2013 in Sarada, Rapti, and Thuli Bheri river basins, and Phewa Watershed Pokhara, Nepal respectively. The decrease in the barren land area is due to the awareness and sustainable forest management programs from different governmental and non-governmental agencies (Tripathi et al., 2020). The concept of bio-engineering for erosion and landslide control has also aided in decreasing the barren land area (Dhital et al., 2013).

Another major increase was observed in the area of the settlement from 0.09% (7.36 ha) to 0.46% (32.70 ha) with a total of 25.7 ha area added (Table 5). Construction of new housing design, farmhouses, schools, and some recreational amenities results in an increment in settlements (Ishtiaque et al., 2017). In addition to these changes, there is a tendency to build new footpaths, roads, and other buildings to improve accessibility and internal movement in the region. Durban, the city of Malika Rural Municipality lies near the outlet of this sub-watershed which is dense and well equipped with different facilities. This results in increasing settlements around the peripheral areas. Rimal et al. (2018) portrays urban centers as the major factor for the increment in settlements in the Kaski district of Nepal. Easy road access to local villages has also fostered the expansion of settlements (Rimal et al., 2015; Adhikari et al., 2018). Additionally, the conversion of forest area into settlements and highways is a result of rapid urbanization (Wang et al., 2020).

The water bodies are minimally decreased during 10 years. The water bodies decreased from 0.27% (18.93 ha) to 0.23% (16.49 ha) with a decrease in the area of 2.5 ha (Table 5). The majority of water springs and streams got displaced or vanished from this area which decreased the area of water bodies (Figure 4). The area coverage of this watershed is more prone to soil erosion and frequent landslides during June-July which causes sedimentation in Ritung Khola, and Ruma Khola via different streams and other water sources that decrease the concentration of water level and purity of natural water. Encroachment of land along rivers by agricultural land is another major cause of declining water bodies (Agaton et al., 2016). Adhikari et al. (2018) study also highlighted that sedimentation and encroachment were the main disturbance to decline the area of water resources in the Phewa watershed, Kaski, Nepal. However, there is the least change in water bodies compared to other classes due to the availability of the same level of water in Ritung Khola and other streams that merged into it.

Impacts of LULC dynamics in springs in Ritung Khola sub-watershed

Further analysis on the impact of LULC changes in springs was performed by FGDs in three selected areas of this sub-watershed. Most of the respondents mentioned that the springs are dried and completely vanished due to the construction of rural roads in different places (Parajuli et al., 2019). Villagers have relied on springs to meet their basic requirements since time immemorial (Ghimire et al., 2019). According to the villagers, “There used to be large number of springs near each house in the past 10 years”. However, in recent years, the villagers have faced water scarcity due to a less number of springs which cannot provide sufficient water to perform daily activities. The study carried out by Sharma et al. (2016) demonstrated a similar result of springs decline in the Mid-hills of Nepal. Also, due to the 2015 earthquake, some springs of this area might have been displaced and completely vanished (Sharma et al., 2016; Chapagain et al., 2019). According to Talchabhadel et al. (2018), the monsoon dominates the rainfall pattern in Nepal, with the four months from June to September receiving about 80% of the country's yearly rainfall. The gap in rainfall pattern also is also a reason for springs' water declination (Miller et al., 2012). The fragile land results in erosion and landslides in different places, which was responsible for the displacement, and drying of the existing springs (Sharma et al., 2016). Chinnasamy and Prathapar (2016) mentioned identical reasons for loss of springs due to spatial variation in geology. The locals predicted that the remaining water springs would be completely lost after 10-15 years if the same trend continues without any conservation practices. The transition matrix (2010-2020) also highlights the decreasing trend of water bodies which indicates that springs are also some sorts of disappearing water resources (Table 6). There is less rainfall during the dry season which lowers the groundwater table that has a direct impact on springs (Gurung and Bhandari, 2009). The decrease in settlement areas by 50% in the last 10 years due to the floods and landslides occurred from Ruma Khola is also a key factor in decline of springs. One-fourth of forest cover decreased due to an increase in settlements over the past 10 years which lead to decrease in the springs from another way. Currently, the conservation status of springs is good from the local people’s perception because the Soil and Watershed Management office, Parbat provides construction aids like gabion and retaining walls which prevents the displacement of spring’s water in a sloppy area, controlling erosion and landslides. The improvement of water reservoirs/rainwater harvesting is necessary for the conservation of different water resources in this area (Adhikari et al., 2021). However, this ought to be the case in the majority of locations as about 80% of Nepal's 13 million inhabitants who live in hills and mountains rely on springs as their main source of water; as a result, they must be conserved by enlisting various conservation programs at all levels, from local to national (Sharma et al., 2016).

The other reason for decline in the springs area was the ongoing construction of rural roads in this area without considering proper conservation techniques (Sharma et al., 2016; Adhikari et al., 2021). The locals themselves create design without consulting the engineer’s team to assess the soil and site geography for roads construction. The ongoing construction of five roads in the Niskot area also hinders the sustainable conservation of the springs and has greater impacts on them. The springs are displaced from their current location due to the recurrent landslides occurred due to road construction (Chapagain et al., 2019). The Bilbang landslide has a severe impact on springs leading to partial loss of springs. The severe landslide pattern also has an impact on the complete loss of springs (Figure 6). Landslides displace the sources of springs and deposit sediments in different river falls in this sub-watershed (for example, Ruma Khola) (Chapagain et al., 2019). The primary source of water for crops and springs in this region is rainfall. However, due to the gap or erratic rainfall patterns, large numbers of springs are drying up rapidly leading to partial loss of springs in this area (Figure 6) (Chaudhary et al., 2011; Tambe et al., 2012; Chapagain et al., 2019; Adhikari et al., 2021). The inconsistent rainfall pattern (high and low) creates a chance of soil erosion and landslides. The decrease in forest cover has parallel links to a decrease in vegetation that ultimately creates a low infiltration rate (Sharma et al., 2016). The roads construction also creates compactness in the soil that eventually decreases the infiltration capacity (Yang and Zhang, 2011). Due to this, the groundwater level and groundwater recharge decrease, which also has an impact on the complete loss of springs (Figure 6). In addition, Government Organizations (GOs), NGOs, INGOs, and CBOs haven't given the conservation priorities for the springs conservation, which has severe impacts on the complete loss of springs (Sharma et al., 2016). There is no provision for rainwater harvesting and tank for water collection during scarcity (Figure 6) (Sharma et al., 2016; Adhikari et al., 2021). People also harvest snow and use the melt water for livestock and irrigation in the highlands of Nepal (Panthi et al., 2019).

Conclusion

LULC practices in the study area have changed dramatically over the past 10 years based on the data acquired through the use of GIS and RS technologies to meet the specific research objectives. Landsat 5 and Landsat 8 satellite with TM and OLI/TIRS sensors were respectively used to classify images. After the classification, the study shows that area of agricultural land, and settlements were increased whereas, forest, water bodies, and barren land had decreased. The discussion of FGDs reveals the significant decrease in springs' number is due to erosion, landslides, road construction, and lack of support from NGOs, INGOs, and CBOs for the sustainable conservation of springs. Forest coverage has decreased from 2010 to 2020; therefore, tree planting should be promoted by the local communities with the help of government offices and non-governmental offices. The water resources are on decreasing trend so; land encroachment near water bodies should be reduced to lessen the depletion of water resources in this sub-watershed. Based on scientific studies, watershed level springs rejuvenation projects should be started by incorporating local people, government organizations, and other stakeholders in order to combat depression and displaced springs. Activities to revive springs, monitoring of water resources, and Integrated Watershed Management (IWM) programs are highly recommended for the conservation of springs' water. The supervised image classification shows decent accuracy for all the classified features. There are some limitations despite having the satisfactory classification result. The research was carried out within a short period using Landsat images of moderate spatial resolution, which could be improved using newer satellite data with finer spatial resolution. In addition, ground truth data were collected based on the 2010 land-use classification types due to the unavailability of latest LULC map. Furthermore, this study might help land-use planners and academicians to formulate the necessary policies for the sustainability of sub-watersheds, whereby conserving the vulnerable springs to reduce water scarcity in local communities.

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