Nitrogen Management Strategies for Enhancing Genotypic Performance and Soil Health in Potato Agroecosystems.

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A field experiment was directed at Agriculture Research Panjgur, Balochistan, during the Rabi season 2022–23 with an RCBD split plot arrangement to find out the effect of different potato genotypes and nitrogen levels on post-harvest soil properties. The potato genotypes, i.e., X1, X2, X3, and X8, are applied to the main plot, while nitrogen levels, i.e., 50, 150, and 250 kg ha-1, are applied to subplots. The effect of different potato genotypes and nitrogen levels is recorded on postharvest soil chemical properties, i.e., pH, electrical conductivity, lime content, organic matter, and texture, as well as soil NPK and carbon level. The crop is harvested at maturity, and samples are collected from all plots, cleaned, packed, labeled, and transpired in a laboratory incubator for analysis. The experiment was arranged in two sites; i.e., site I has only the effect of genotypes, while site II has the effect of genotypes as well as different nitrogen levels. The sample analysis at site-I reveals that the X7 genotype increases the EC, while the X7 genotype increases PH. The plot with a genotype of X8 showed the highest levels of organic matter, N, and P, while the plot with a genotype of X3 showed the highest levels of mineral nitrogen. Gen was observed in the plot with a genotype of X3. The highest results at site II indicate that different nitrogen levels and genotypes have exhibited different behaviors on the soil EC. Rogen levels and genotypes have behaved^{-1}ifferently on soil EC. The maximum EC was recorded at 250 kg ha1 of N, while the minimum was recorded at 50 kg ha1, while the response of the genotype to the nitrogen level on the soil pH is trending upwards as N levels increase, and the genotype X5 exhibits the highest response to nitrogen levels on PH. Genotype on nitrogen levels on pH, X5, gives the maximum value. The phosphorus and potassium give the same response to genotype; the maximum value of both is observed in the Xha^{-1}. The plot that received 150 kg ha-1 showed the highest K levels. 1. and maximum k was observed in the plot received 150 kg ha-1. The response to N fertilizer is the same in OM, and mineral N obtained the maximum value at 150 kg ha^{-1}, while phosphorus gave the maximum value at 50 kg ha^{-1}.50 kg ha1, while phosphorus gave the maximum value at 50 kg ha1.sss

Randomized Complete Block Design	RCBD
Kilograms per hectare	kg ha-1
Electrical Conductivity	EC
Nitrogen, Phosphorus, and Potassium	NPK
Organic Matter	OM
Nitrogen	N
Phosphorus	P
Potassium	K
Diammonium Phosphate	DAP
Sulphate of Potash	SOP

Keywords: Potatoes, Genotypes, Nitrogen, Fertilizers, Soil Properties.

Introduction:

Potatoes, scientifically termed Solanum tuberosum L., belong to the Solanaceae family and rank as the fourth most vital crop globally in terms of production [1]. Its cultivation spans numerous countries, making it a versatile food source for humans and animals, as well as a crucial component in starch and alcohol manufacturing [2]. This multifaceted role has earned it the moniker "king of vegetables [3]. Potatoes are of high nutritional value, being a natural source of carbohydrates, vitamins, and minerals [4] and [5]. The inherent soil health and environmental pollution, which result from mismanaging potato cropping systems due to excessive use of agricultural chemicals, directly influence the growth, yield, and nutritional quality of potatoes [6] and [7]. Nitrogen is a crucial nutrient for potatoes, as it is the key component in the production of chlorophyll, accelerating the completion of photosynthesis, and therefore has a direct influence on the growth process and the formation of tubers [8]. In Pakistan, potato production is self-sufficient, with roughly 149 thousand hectares devoted to its cultivation [9] and [10]. Pakistan produces approximately 2.02 million metric tons annually, using 280,000 metric tons for seeding and 1.7 million metric tons for food consumption and industrial purposes. With a population of around 150 million, this equates to roughly 14 kilograms per capita per year [11]. Punjab, particularly in regions like Okara, Sahiwal, Kasur, and Sialkot, primarily concentrates about 86% of Pakistan's potato cultivation. Khyber Pakhtunkhwa (KPK) accounts for 9% of the remaining production, Baluchistan for 4.5%, and Sindh for 0.5%. Potatoes serve as a staple food due to their nutritional profile, with water comprising 75 to 80%, carbohydrates 16–20%, crude protein 2.5–3.2%, and other essential nutrients [12] and [13]. Effective nitrogen fertilization is pivotal for maximizing potato yield and quality, as insufficient nitrogen levels can result in stunted growth and reduced yields [14] and [15]. Pakistan typically harvests its primary potato crop in February or March, and prices remain low until May when they begin to increase [16], [17], and [18]. To safeguard against quality and weight loss during storage, many potatoes are promptly transferred to cold stores post-harvest and gradually released for sale [19]; [20], and [21]. Climate change poses a substantial challenge to the agricultural sector, affecting crop production and food security [22]. Identifying suitable potato varieties for different seasons, such as spring, can help alleviate some of these challenges and ensure a consistent supply of fresh potatoes for consumption [23]. Salinity affected about 20 to 25% of the entire world and 26% of the irrigated agricultural land in Pakistan [24]. Global warming is gradually increasing salinity due to increased evapotranspiration, which necessitates more irrigation. Consequently, the rhizosphere is accumulating more salts, especially in dry and rainfed regions of Earth [25]. NaCl accumulation salinates about 50–80% of the area [26] and [27]. Na ions also reduce K acceptance, which ultimately leads to water loss. Sodium ions enter the leaf through the apoplast from the xylem stream and then undergo evaporation. Sodium ions generally reside in cation-binding sites by dropping the uptake and transport of Ca and K [28]. Salinity is a severe problem as it disturbs plant growth and productivity. According to [29], salinity changes many metabolic processes that are good for plant growth and makes some ions more toxic. It also lowers water potential and makes stomatal conductivity and respiration worse. Plants exposed to salt stress primarily collect Na and Cl ions in their tissue, which impact various physiological processes such as plasmolysis and ultimately restrict plant growth [30], [31], [32], and [33].

Objectives and Novelty:

The present study was conducted to evaluate the impact of different nitrogen levels and potato genotypes on the post-harvest properties of soil, namely pH, electrical conductivity, organic matter, and nutrient levels to improve soil health and potato agroecosystem. The research aimed to improve nitrogen management practices to enhance both soil quality and crop yield in potato farming.

Materials and Methods:

An experimental investigation was conducted to assess the influence of various potato varieties and differing nitrogen levels on soil quality post-harvest at the Agriculture Research Panjgur, Balochistan, during the Rabi season of 2022–23. Three replications of the study used a randomized complete block design with a split-plot arrangement. Main plots were dedicated to distinct potato genotypes, while subplots were designated for varying nitrogen levels. Each treatment plot measured 4x5 m². Before planting, the land underwent double plowing, and fertilizers such as DAP and SOP were uniformly applied to all plots, including the control plot. DAP was utilized as a phosphorus source at a rate of 100 kg P2O5 ha-1, while SOP served as a potassium source at a rate of 100 kg ha-1. Nitrogen fertilizers, in the form of urea, were applied at rates of 50, 150, and 250 kg N ha^{-1} to the subplots as per the assigned treatments. The site was then rolled and power-harrowed for preparation. The day before planting, we fashioned beds and conditioned the soil by eliminating clods to create a narrow channel. Trenches were formed using a moldboard plow with a depth of 0.3 mm in each row. Seeds of different potato genotypes were manually planted at a depth of 200 mm in the row and hand-molded. Plant spacing was set at 35 cm within the same row and 80 cm between rows. All essential cultural practices, including irrigation and weed management, were implemented following standard regional procedures.

Main Plot Factor (Potato Genotypes):

X1, X2, X3, X8

Subplot Factor Nitrogen Levels:

50, 150, and 250 kg ha^{-1}

Soil Analysis:

At maturity, all plots were harvested using a single-row digger. Soil samples were collected with agar from each plot at a depth of 0–15 cm. The collected samples were clean, packed, and labeled. The sample was kept in an incubator in the laboratory for analysis.

Soil PH:

Soil pH analysis was conducted according to the method described by McClean in 1982, involving the creation of a 1:5 soil-water suspension. This method entailed dissolving 10 grams of soil in 50 milliliters of distilled water, followed by shaking the solution for 50 minutes and subsequent filtration. Before analyzing the soil samples, calibration of the pH meter was carried out using buffer solutions with pH values of 10.01 and 7.00. To ensure precision in readings, the electrode was rinsed with distilled water and the subsequent sample before each measurement. The pH measurements were documented using a WTW PH meter.

Soil Electrical Conductivity:

The soil suspension extract obtained for pH measurement was also utilized to determine the soil's electrical conductivity (EC). The EC analysis of the soil samples followed the procedure outlined by Richard in 1954. Before conducting the tests on the soil samples, the EC meter (manufactured by WTW) underwent calibration using a 0.1 N KCl solution.

Soil Organic Matter:

The soil's organic matter content was assessed using the wet combustion method developed by Walkley and Black, as outlined in the study by [34]. For the analysis, one gram of air-dried soil sample was combined with 10 ml of 1 N K2Cr2O7 solution and 20 ml of concentrated H2SO4. Following the addition of 200 ml of distilled water, the mixture underwent filtration and titration against a 0.5 N FeSO4 solution, with ortho-phenolphthalein serving as the indicator until reaching the endpoint. Additionally, a blank sample was prepared and analyzed alongside the soil samples.

Soil Lime Content (%):

A soil sample weighing 5 grams was placed into a flask, to which 50 milliliters of 0.1N hydrochloric acid were added. The flask was covered with a watch glass, and the solution was heated on a hot plate for 10 minutes before cooling, filtration, and titration with 0.25N sodium hydroxide solution until a pink color appeared. The lime percentage was determined using the formula (S-B) multiplied by 0.05, then multiplied by 100, where S represents the reading of the samples, B represents the reading of the blank used to adjust the normality of the sodium hydroxide, and 0.05 denotes the equivalent weight of calcium carbonate. This method was originally described by [35].

Soil Texture:

The soil's composition was analyzed using the hydrometer technique [36] by taking 50 g of soil samples in the dispersion for 5 minutes after transferring them into a 1L cylinder. The hydrometer and thermometer readings were taken once after 40 seconds and then after 2 hours.

Mineral Nitrogen in Soil:

The mineral nitrogen content in a soil sample was determined following the procedure outlined by [37]. In this method, 20 grams of soil sample were mixed with 100 milliliters of 1M KCl solution and shaken for an hour. After filtration, 20 milliliters of the resulting extract underwent distillation with 0.2 grams of MgO to recover NH4-N. Additionally, MgO, along with Devarda's alloy, was utilized to recover both NH4-N and NO3-N. The distilled liquid was collected in a solution containing boric acid and an indicator and then titrated against 0.005 M HCl. The nitrogen content was determined based on the equivalence point, where 1 milliliter of 0.005 N HCl corresponded to 70 micrograms of nitrogen. The concentration of NO3-N was obtained by subtracting the NH4-N content from the total nitrogen content.

Ab-Dtpa Extractable P in Soil:

The AB-DTPA-extractable phosphorus was obtained utilizing the method recommended by [38]. In this procedure, a 10g soil sample was mixed with 20 mL of AB-DTPA solution at a pH of 7.56. The mixture was gently shaken on a reciprocating shaker for 30 minutes in open-mouthed 250-mL conical flasks before filtration through the Whatman No. 42 filter paper. The phosphorus content in the samples was determined using the NH4-molybdate complex method. For phosphorus content analysis, one mL of the extract was combined with 4 mL of distilled water and 5 mL of ascorbic acid phosphorus mixed reagent. The volume was adjusted to 25 mL with additional distilled water. A blank and five standards containing 2, 4, 6, 8, and 10-mL P L-1 were prepared using the same procedure to establish a standard absorption curve on a spectrophotometer at a wavelength of 880 nm. The concentration of phosphorus in the soil was determined on a dry-weight basis using the standard absorption curve.

Ab-Dtpa Extractable K:

The soil's potassium content was evaluated using the AB-DTPA extraction method specified by Soltan pour and Schwab in 1977. Subsequently, potassium levels were determined using a flame photometer (Jen way PFP 7).

Statistical Analysis:

Statistical analysis of data concerning various plant parameters, soil nutrient concentrations, and nutrient accumulation in plant leaves during the anthesis stage and grains was performed using ANOVA techniques within the framework of the randomized complete block design. To ascertain significant differences among the treatments, means were compared using the least significant difference (LSD) test. The analysis was conducted using the Statistics 2000 computer software.

Results and Discussion:

N Levels and Potato Genotypes Affect Soil EC:

The post-harvest soil EC was affected by different levels of nitrogen, and the genotypes of potatoes at two different locations were not significantly affected, as shown in Table 1 and Figure 1. The results showed that genotypes of potatoes at site-I affected the EC, which ranged from 0.70 to 1.4. The maximum EC value of 1.4 was observed in treatment with

X4, followed by X3 and X1, with values of 1.23 and 1.12, respectively, while the minimum value was recorded in the X7 genotype. The effect of nitrogen levels on EC at site II is increasing, with nitrogen levels ranging from 0.87 to 0.96. The maximum mean value of 0.96 EC was recorded in the plots receiving 250 kg ha^{-1} of N, followed by the plot receiving 150 kg ha-1 of N, while the minimum was in the plots receiving 50 kg ha-1 of N. However, the result of nitrogen level on genotype was quite different from site I; the maximum value of EC (1.06) was obtained from the plot having genotype X3, while X4 and X5 have given almost the same values. The minimum value of EC (0.84) was recorded from two plots with genotypes X7 and X8.

Table 1. Effect of N level on different genotypes on postharvest soil EC at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
		50	150	250	
X1	1.12	0.70	0.89	0.83	0.88
X2	0.90	0.83	0.82	1.04	0.90
X3	1.23	0.97	0.95	1.08	1.06
X4	1.40	0.89	0.94	0.83	1.01
X5	0.86	1.01	0.95	1.29	1.03
X6	1.09	0.98	0.87	0.68	0.90
X7	0.70	0.74	1.06	0.88	0.84
X8	0.73	0.83	0.72	1.09	0.84
Mean	1.00	0.87	0.90	0.96	

The values are composite values of three replications and hence no statistics were done.

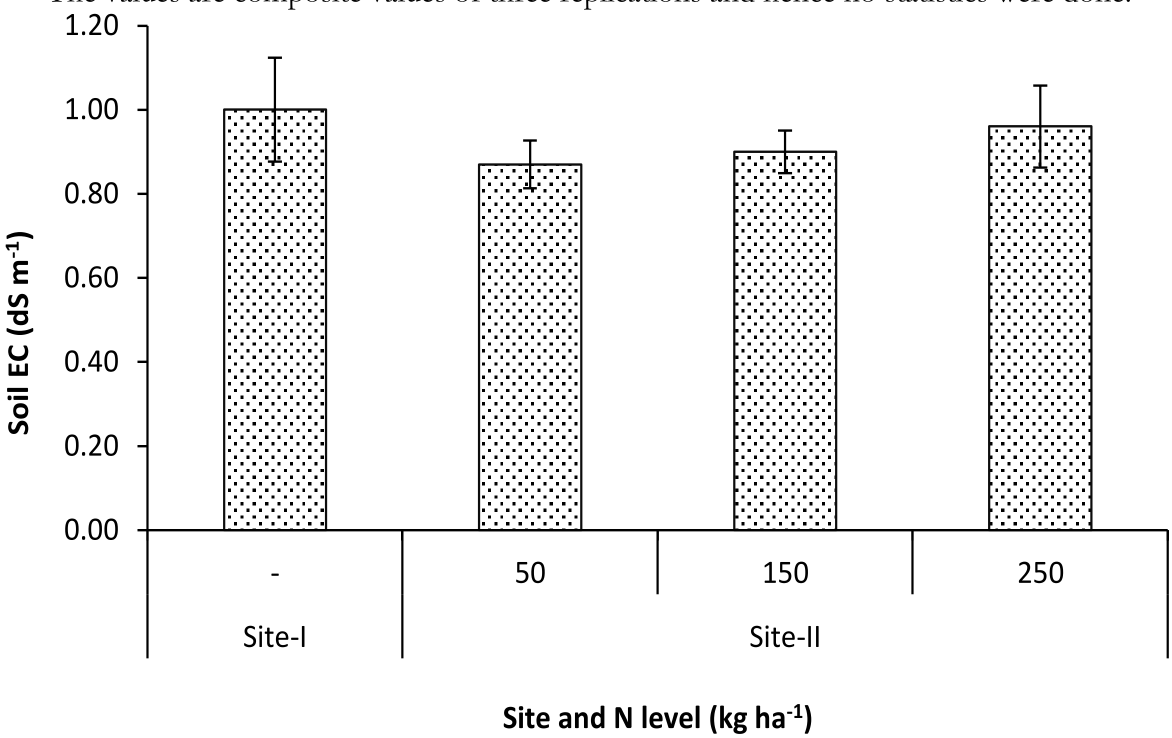


Figure 1. Effect of N level on different genotypes on postharvest soil EC at two different locations

N Levels and Potato Genotypes Affect Soil PH:

The value of postharvest soil pH as influenced by different genotypes of potato and the application of N at different levels is shown in Table 2. and Figure 2. Site-I has a pH range of 7.45 to 7.59, and at site-II, the pH calculated was 7.41 to 7.68. The highest pH was observed at genotype X6, with a value of 7.59 when averaged on location and N levels, while the lowest pH was observed at genotype X4, with a value of 7.53. The soil pH showed an increasing trend with the application of different levels of N. At site II, the pH increased with the levels of N. The pH increased from 7.55 at 50 kg N ha1 to 7.56 at 150kg N ha1, and further, by increasing the level to 250 kg N ha1, the pH increased to 7.60. The same trend has been shown in the table. The pH of soil at 50 kg N ha-1 was ± 0.87 SD, which decreased to o.o.4 SD at 250 kg N ha-1.

Table 2. Effect of N level on different genotypes on postharvest soil pH at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
	-	50	150	250	
X1	7.54	7.54	7.59	7.55	7.56
X2	7.53	7.53	7.52	7.60	7.55
X3	7.49	7.64	7.56	7.61	7.58
X4	7.51	7.41	7.63	7.56	7.53
X5	7.45	7.62	7.43	7.68	7.55
X6	7.50	7.67	7.60	7.58	7.59
X7	7.59	7.43	7.67	7.59	7.57
X8	7.58	7.58	7.48	7.61	7.56
Mean	7.52	7.55	7.56	7.60	

The values are composite values of three replications and hence no statistics were done.

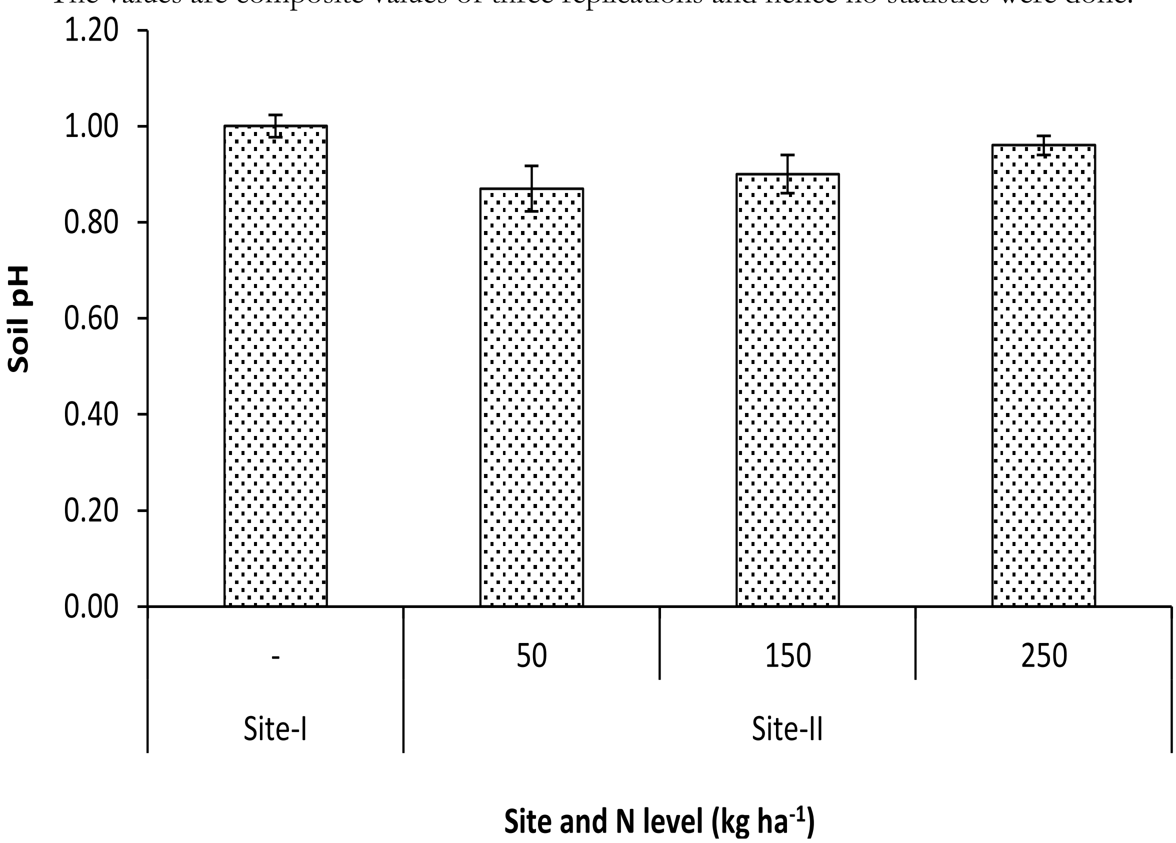


Figure 2. Effect of N level on different genotypes on postharvest soil pH at two different locations

N Levels and Potato Genotypes Affect Soil Organic Matter:

The value of postharvest soil organic matter as influenced by different genotypes of potato at two different locations and N levels is shown in Table 3 and Figure.3. In site-I, where only one level of N fertilizer is applied, organic matter ranges from 1.12 to 2.25 percent;

the highest value (2.25%) was observed in the X8 genotype, followed by X7 and X6 with values of 1.93 and 1.93, respectively. While the minimum was recorded in the X4 genotype with a value of 1.12%. The response of N level and genotypes on organic matter was observed in Site II. The average highest value (1.77%) was recorded from the plot receiving 150 mg kg-1, closely followed by 1.69% in the plot receiving 250 kg ha^{-1} of N fertilizer, while the lowest (1.51%) was recorded from the plot receiving 50 kg ha-1 of N. While the response of genotypes under different N levels is different from site-I, the maximum value of 1.93% of OM was recorded from a plot with genotype X2 very closely followed by X4 with a value of 1.92%. The minimum value of OM (1.52%) was recorded in X8.

Table 3. Effect of N level on different genotypes on postharvest soil organic matter at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
		50	150	250	
X1	1.80	1.93	2.09	1.77	1.89
X2	1.67	1.45	2.34	2.25	1.93
X3	1.28	1.60	2.09	1.77	1.68
X4	1.12	2.09	2.41	2.06	1.92
X5	1.60	1.20	1.93	1.22	1.49
X6	1.96	1.44	0.71	1.77	1.47
X7	1.93	1.12	1.35	1.40	1.45
X8	2.25	1.28	1.28	1.28	1.52
Mean	1.70	1.51	1.77	1.69	

The values are composite values of three replications and hence no statistics were done.

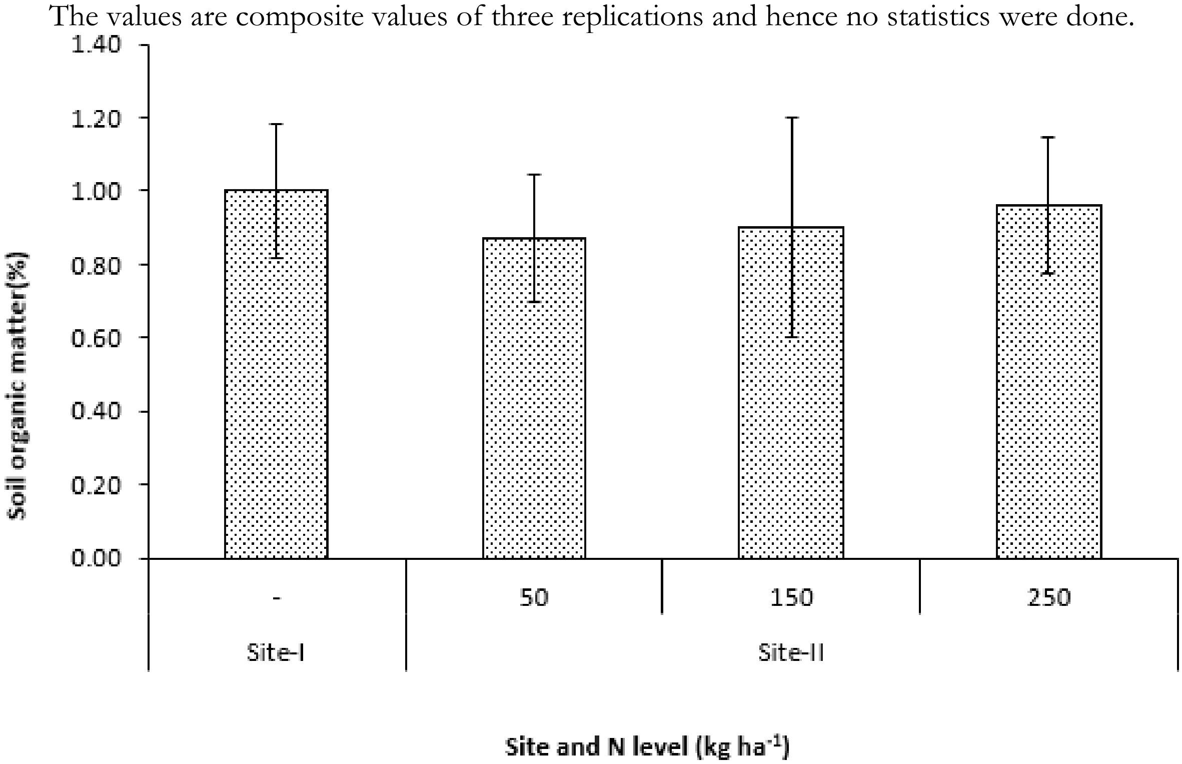


Figure 3. Effect of N level on different genotypes on postharvest soil organic matter at two different locations

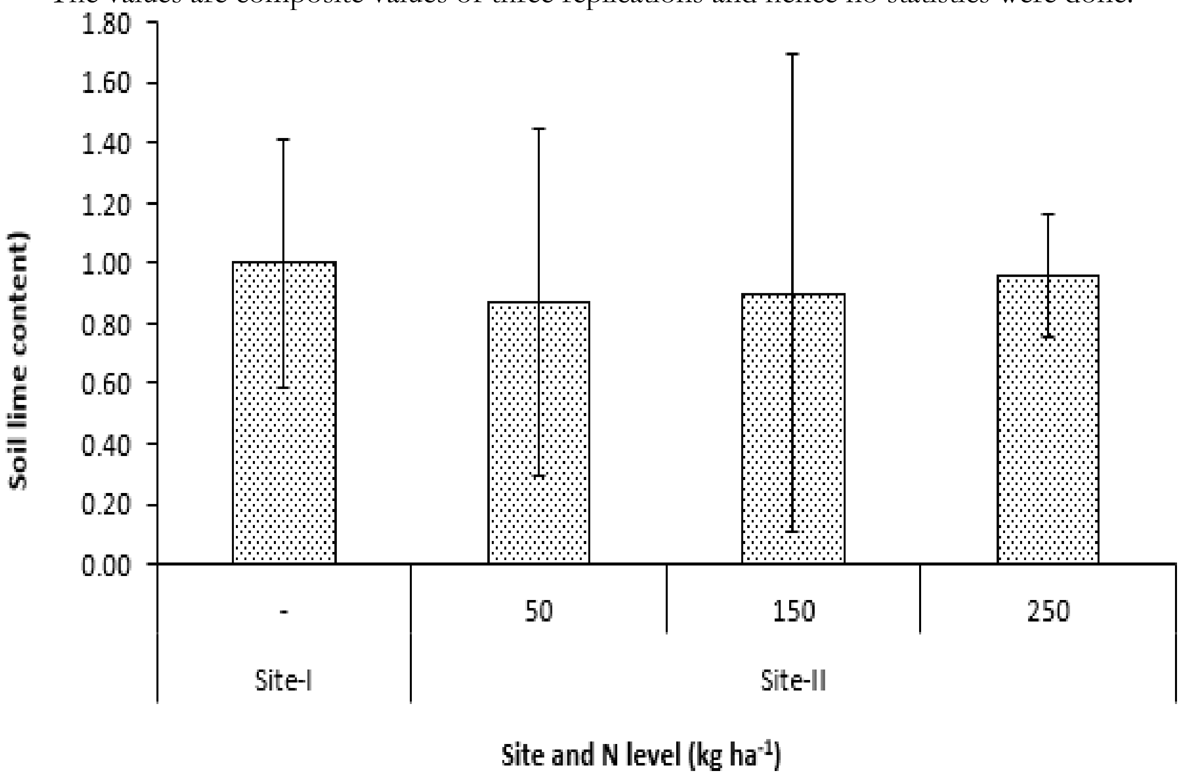
N Levels and Potato Genotypes Effect on Lime Content (%):

The value of postharvest soil lime content as influenced by different genotypes of potato at two different locations and N levels is shown in Table 4 and Figure 4. In site-I, where only one level of N fertilizer is applied, the lime content ranges from 20.3 to 23.6%; the highest value (23.6%) was observed in the X4 genotype, followed by X1 and X6, with values of 22.8 and 22.5 percent, respectively. While the minimum was recorded in the X3 genotype with a value of 20.3%. The response of N level and genotypes on lime content was observed in Site II. The average highest value (22.4%) was recorded from the plot receiving 250 mg kg-1, closely followed by 22.3% in the plot receiving 150 kg ha^{-1} of N fertilizer, while the lowest (22.0%) was recorded from the plot receiving 50 kg ha-1 of N. Overall, the result shows an increasing trend with increasing N fertilizers. While the response of genotypes under different N levels is different from site-I, the maximum value of 22.5% of lime content was recorded from the plot having genotype X5, while the minimum value of lime content (21.8%) was recorded in X3. Overall, all the values of all the genotypes were closer to each other, the difference was negligible compared to site I.

Table.4. Effect of N level on different genotypes on postharvest soil lime content (%) at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
		50	150	250	
X1	22.8	20.5	22.3	22.7	22.1
X2	21.6	23.3	21.0	22.8	22.2
X3	20.3	22.7	22.3	22.1	21.8
X4	23.6	21.0	22.7	22.6	22.5
X5	21.7	21.7	21.9	23.5	22.2
X6	22.5	23.0	22.6	21.3	22.3
X7	21.7	21.7	22.7	22.1	22.1
X8	22.4	21.9	22.5	22.3	22.3
Mean	22.1	22.0	22.3	22.4	

The values are composite values of three replications and hence no statistics were done.



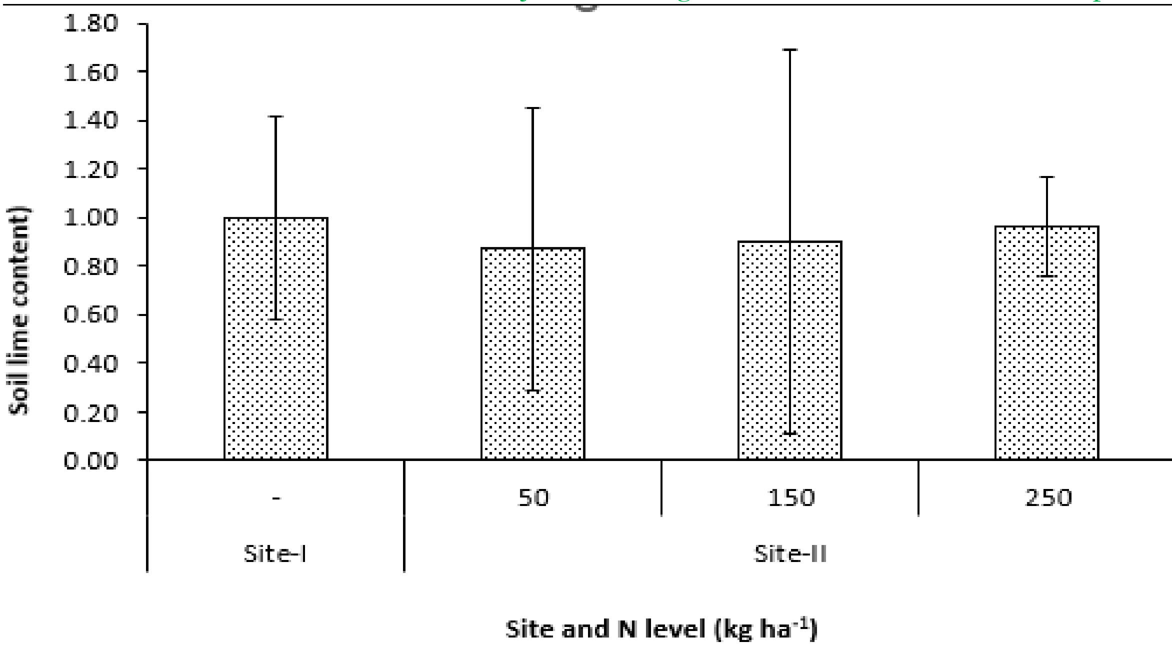


Figure 4. Effect of N level on different genotypes on postharvest soil lime content (%) at two different locations

N Levels and Potato Genotypes Affect Soil Mineral N:

The result for postharvest soil mineral N as affected by potato genotypes and different levels of soil-applied N is shown in Table 5 and Figure 5. In site-I, where the nitrogen level is the same, the effect of the potato genotype on soil mineral N ranges from 34.2 mg kg^{-1} to 61 mg kg-1, with a maximum value of 61 mg kg^{-1}in a plot with the X3 genotype, followed by X1 with a value of 56 mg kg-1, while X1 is followed by X4 and X8 with the same value of 47 mg kg^{-1}. The minimum value at site-I was obtained from the plot having genotypes X2 and X7 with the same value of 34 mg kg^{-1}. The site-II mineral N as an effect of genotype with different nitrogen levels is observed to be variable, ranging from 29.8 mg kg1 to 56.9 mg kg1. The mean maximum value of 47 mg kg1 was recorded in plots where 150 kg ha1 of N was applied, followed by plots receiving 250 kg ha1 of N with 45 mg kg1, while the lowest mean value was recorded at a nitrogen level of 42 mg kg1 obtained from plots receiving 50 kg ha1. However, the result of nitrogen level on genotype was quite different from site I. The maximum value of mineral N was obtained from X1, X3, X4, and X8 having the same value (48 mg kg^{-1}) while the minimum value of mineral N (40 mg kg^{-1}) was recorded from the plot having genotype X5 (Figure 4.5).

Table.5. Effect of N level on different genotypes on postharvest soil mineral N (mg kg^{-1}) at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
		50	150	250	
X1	56.1	49.1	42.1	48.2	48.9
X2	34.2	38.6	48.2	40.3	40.3
X3	61.3	37.7	39.4	56.1	48.6
X4	47.3	51.7	56.9	37.7	48.4
X5	43.0	29.8	47.3	39.4	39.9
X6	44.7	39.4	42.1	38.6	41.2
X7	34.2	51.7	56.1	47.3	47.3
X8	47.3	43.0	47.3	56.9	48.6
Mean	46.0	42.6	47.4	45.6	

The values are composite values of three replications and hence no statistics were done.

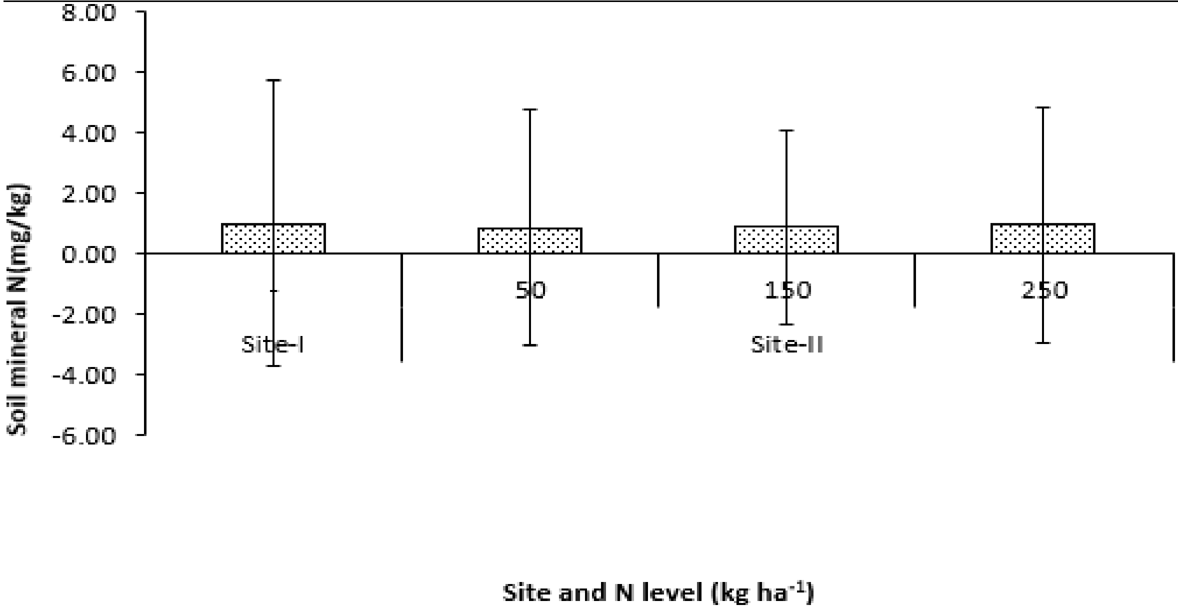


Figure 5. Effect of N level on different genotypes on postharvest soil mineral N (mg kg^{-1}) at two different locations

N Levels and Potato Genotypes Affect Soil AB-DTPA Ext. P:

The post-harvest soil AB-DTPA ext. P was affected by different levels of nitrogen, and genotypes of potatoes at two different locations were significantly affected, as shown in Table 6 and Figure 6. The results showed that genotypes of potato at site-I affected the AB-DTPA ext. P, which ranged from 1.93 to 4.29. The maximum AB-DTPA ext. P value of 4.29 was observed in treatments having genotype X8, followed by X7 and X2 with values of 3.71 and 3.63, respectively, while the minimum value (1.93) was recorded in the X1 genotype. The effect of nitrogen levels on AB-DTPA ext. P at site II was in a decreasing trend, increasing with nitrogen levels ranging from 2.70 to 3.88. The maximum mean value of 3.88mg AB-DTPA ext. P was recorded in the plots receiving 50 kg ha^{-1} of N, followed by the plot receiving 150 kg ha-1 of N, while the minimum value (2.70) was in the plots receiving 250 kg ha-1 of N. However, the result of the nitrogen level on genotype at site II was quite different from that at site I. The maximum value of AB-DTPA ext. P (3.88) was obtained from the plot having genotype X7, followed by a value of 3.7 obtained from the two genotypes X2 and X3. The minimum value of AB-DTPA ext. P (2.70) was recorded from two plots having genotype X3. The soil AB-DTPA ext. P was ±1.16 SD at 50 kg N ha-1, which decreased to ± 0.41 SD at 250 kg N ha^{-1}. The trend is shown in Figure 4.5.

Table 6. Effect of N level on different genotypes on postharvest soil AB-DTPA extractable phosphorus at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
	-	50	150	250	
X1	1.93	4.39	2.15	2.52	2.75
X2	3.63	5.16	2.79	3.24	3.71
X3	2.80	2.57	2.68	2.74	2.70
X4	1.96	3.27	6.20	3.17	3.65
X5	3.27	2.45	5.01	3.81	3.63
X6	3.12	5.25	1.98	2.93	3.32
X7	3.71	4.13	5.07	2.63	3.88
X8	4.29	2.61	2.88	3.06	3.21
Mean	3.09	3.73	3.59	3.01	

The values are composite values of three replications and hence no statistics were done.

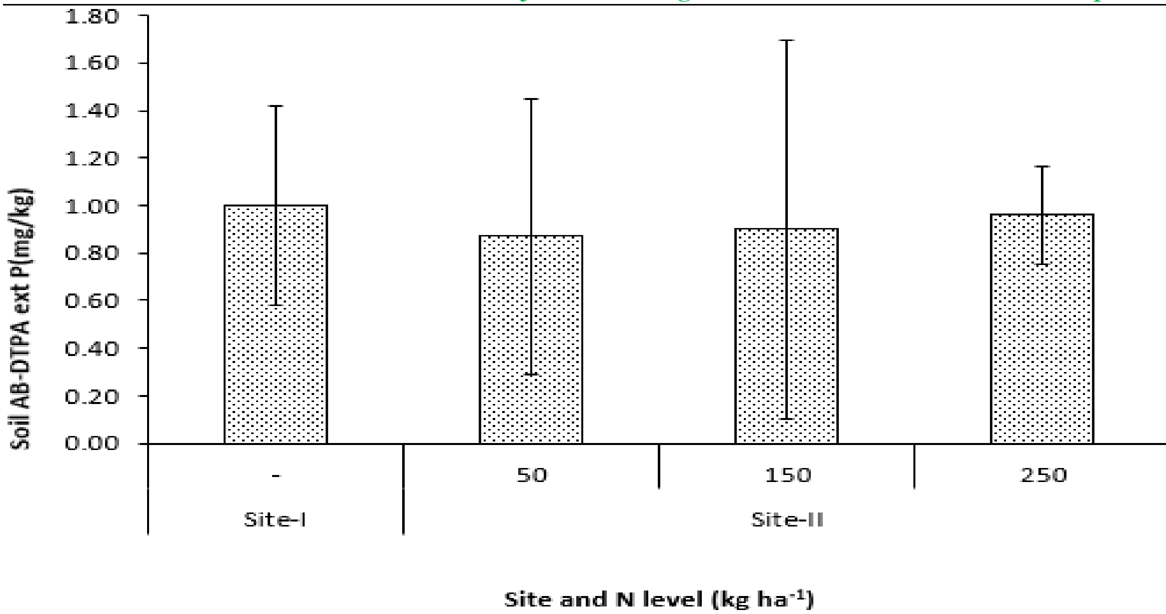


Figure 6. Effect of N level on different genotypes on postharvest soil AB-DTPA extractable phosphorus at two different locations.

N Levels and Potato Genotypes Affect Soil AB-DTPA Ext. K:

The value of postharvest soil AB-DTPA extractable K as influenced by different genotypes of potato at two different locations and N levels is shown in Table 7 and Figure 7. In site I, where only one level of N fertilizer is applied, K ranges from 215 to 425 mg kg^{-1}. The highest value (425 mg kg^{-1}) was observed in the X8 genotype, followed by the X7 with a value of 414 mg kg-1, while the minimum was recorded in the X5 genotype with a value of 215 mg kg^{-1}. The response of N level and genotypes to K was observed in Site II. The average highest value (333 mg kg^{-1}) was recorded from the plot receiving 150 mg kg-1, closely followed by 332 mg kg^{-1} in the plot receiving 50 kg ha^{-1} of N fertilizer, while the lowest (302 mg kg^{-1}) was recorded from the plot receiving 250 kg ha-1 of N. While the responses of genotypes under different N levels are different from site-I, the maximum value of 363 mg kg1 was recorded from the plot having genotype X7, followed by X3 and X1 with the same value of 360 mg kg1. The minimum value of K (257 mg kg^{-1}) was recorded in X4.

Table 7. Effect of N level on different genotypes on postharvest soil AB-DTPA extractable potassium at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			
	-	50	150	250	Mean
X1	374	419	288	360	360
X2	319	348	273	397	334
X3	373	442	366	259	360
X4	371	256	278	123	257
X5	215	293	434	383	331
X6	295	282	264	394	309
X7	414	386	401	252	363
X8	425	229	357	246	314
Mean	348	332	333	302	

The values are composite values of three replications and hence no statistics were done.

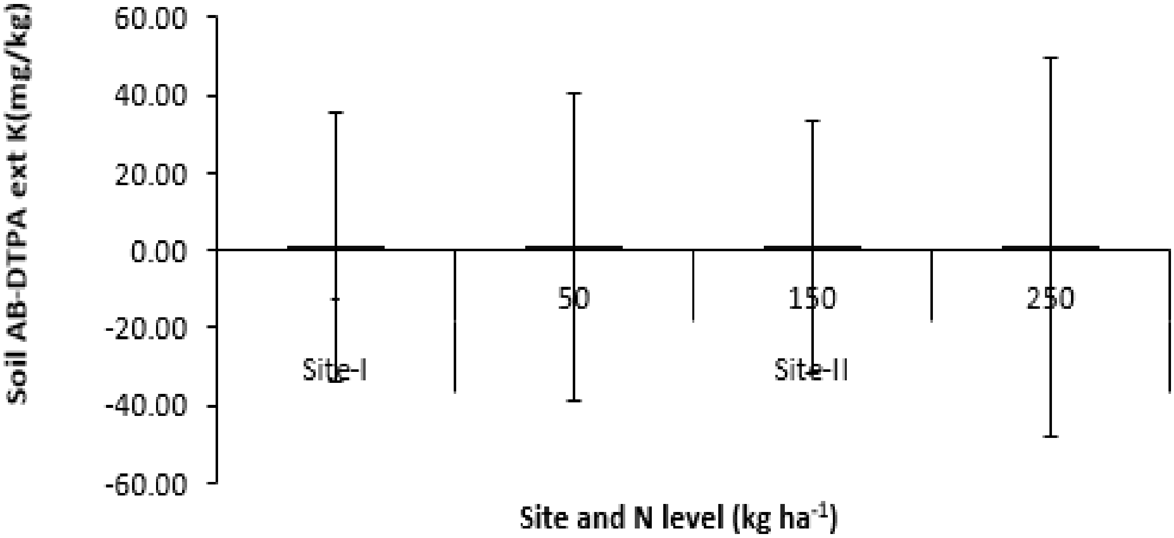


Figure 7. Effect of N level on different genotypes on postharvest soil AB-DTPA extractable potassium at two different locations

N Levels and Potato Genotypes Affect Soil Clay Content (%):

The value of postharvest soil silt content as influenced by different genotypes of potato and the application of N at different levels is shown in Table 8 and Figure 8. Site-I has a silt range of 24% to 18%, and at Site-II, the pH calculated had a range of 30% to 22%. The highest clay content was observed at genotypes X1 and X8, with a value of 27% when averaged by location and N levels, while the lowest silt content was observed at genotype X4, with a value of 24%. The soil clay showed an increasing trend with the application of different levels of N. At site II, the clay content increased with the levels of N. The clay increased from 26% at 50 kg N ha-1 to 150 kg N ha-1, and further, by increasing the level to 250 kg N ha-1, the clay increased to 28%. The same trend has been shown in the table. The clay of the soil at 50 kg N ha-1 was ± 2.17 SD, which increased to 2.78 SD at 150 kg N ha^{-1}.

Table.8. Effect of N level on different genotypes on postharvest soil clay (%) at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			Mean
		50	150	250	
X1	21	26	30	30	27
X2	20	27	24	28	25
X3	22	30	22	26	25
X4	22	22	26	26	24
X5	18	26	26	28	25
X6	18	26	30	26	25
X7	24	26	26	28	26
X8	24	26	28	28	27
Mean	21	26	27	28	

The values are composite values of three replications and hence no statistics were done.

N Levels and Potato Genotypes Affect Soil Silt Content (%):

The result for postharvest soil silt content as affected by potato genotypes and different levels of soil-applied N is shown in Table 9 and Figure 9. The site-I had a soil silt range of 22% to 19%, while the site II had a soil silt range of 19% to 13%. Among the genotypes and N levels, the highest result was recorded at genotype X8, with a value of 19%.

The lowest result was recorded at genotype X2 with a value of 15%. The graph is shown below. The silt content at 50 kg N ha-1 was ±2.26 SD, which increased to ±2.33 SD at 250 kg N ha-1.

Table.9. Effect of N level on different genotypes on postharvest soil silt content (%) at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			
	-	50	150	250	**Mean**
X1	20	13	16	16	16
X2	19	13	12	16	15
X3	22	16	16	16	18
X4	23	19	16	18	19
X5	22	14	19	12	17
X6	22	15	16	16	17
X7	22	17	18	12	17
X8	22	18	17	18	19
Mean	22	16	16	16	

The values are composite values of three replications and hence no statistics were done.

N Levels and Potato Genotypes Affect Soil Sand Content (%):

The value of postharvest soil sand content as influenced by different genotypes of potatoes at two different locations and N levels is shown in Table 10 and Figure 10. Where sand ranges from 61% to 54% at site-I and from 66% to 52% at site-II when averaged on location and N levels, the mean highest sand was observed in genotype X6 with a value of 60%. The lowest value was observed in genotypes X8 with a value of 55%. . . The sand of the soil at 50 kg N ha-1 was ± 4.82 SD, which decreased to 3.81 SD at 150 kg N ha-1.

Table.10. Effect of N level on different genotypes on postharvest soil sand content (%) at two different locations

Genotype	Site-I	Site-II (N levels, kg ha^{-1})			
	-	**50**	**150**	**250**	**Mean**
X1	59	61	54	54	57
X2	61	60	64	50	59
X3	56	54	56	58	56
X4	55	59	58	52	56
X5	60	50	55	60	56
X6	60	66	54	58	60
X7	54	57	62	60	58
X8	54	56	55	54	55
Mean	57	58	57	56	

The values are composite values of three replications and hence no statistics were done.

Discussion:

An agricultural experiment was carried out to study the impact of various potato genotypes and nitrogen levels on the soil properties after harvesting at Agriculture Research Panjgur in Balochistan during the Rabi season of 2022–23. The experiment was set up in a randomized complete block (RCB) design with a split-plot arrangement and three replications. The main plots were designated for different potato genotypes, while the subplots were assigned different levels of nitrogen. Each treatment plot had a size of 4x5 m2. The land was plowed twice to prepare the beds, and DAP fertilizer was applied at a rate of 100 kg P2O5 ha-1, while SOP fertilizer was applied at a rate of 100 kg ha-1 to all plots, including the control plot. Nitrogen fertilizers in the form of urea were applied at rates of 50, 150, and 250 kg N ha-1 to the subplots based on the treatment. The site was then rolled and power-harrowed. The day before planting, beds were formed, and the soil was conditioned by removing clods to create a narrow channel. A trench with a depth of 0.3 mm was created in each row using a moldboard plow. The potato seeds of different genotypes were hand-planted at a depth of 200 mm in the row and then hand-molded. The spacing between plants was 35 cm within the same row and 80 cm between rows. All cultural practices, such as irrigation and weed control, were carried out according to the standard procedures of the region. The study evaluated the impact of potato genotypes and nitrogen levels on soil properties after harvesting. The proximate composition and energy value of the various potato varieties were analyzed, showing the significant effects of fertilization treatments and genotypes on the tested parameters. Previous studies have also highlighted the influence of different NPK fertilizer levels on the proximate composition of potato crops, indicating that fertilizer rates can significantly affect the composition of potatoes. Similar results have been reported regarding the impact of nitrogen fertilizers on sweet potato crops. In a recent study conducted by [39], it was observed that the levels of carbohydrates and protein in potatoes varied significantly depending on the type and quantity of nitrogen fertilization applied. This finding aligns with earlier research by [40]. Potatoes are recognized as a notable source of essential amino acids such as lysine, leucine, phenylalanine, and threonine, which are essential for human health since they cannot be synthesized internally. Potato protein comprises seven out of the eight externally consumed amino acids, rendering it a valuable protein source [41]. Typically, the overall protein content in potatoes ranges from 1.5% to 2.3% of their fresh weight, with a notable proportion of this protein being of high quality. However, in comparison to legumes like peas, which contain approximately 9.01g of protein per 100g, potatoes exhibit lower protein content [42]. Nevertheless, the consumption of potatoes can still fulfill essential amino acid requirements, particularly for individuals adhering to a vegan diet [43]. Research by [44] and [45] revealed that potato protein content ranged from 7.54% to 11.37% and from 9.54% to 10.19% on a dry weight basis, respectively. In our investigation, protein content levels ranged from 99.1g to 114.4g per kg of dry matter in potato tubers. The highest protein levels in potato tubers were observed when employing green fertilizers such as fodder peas in combination with a full NPK dose and biological fertilizer. Moreover, the utilization of bio-fertilizers, particularly in conjunction with straw, led to increased protein content in tubers compared to those treated with only half the mineral fertilization dose. It was also noted that both fodder peas and straw contributed to enhancing soil productivity and fertility [46]. The dry matter composition of potato plant tissues, including shoots and tubers, can vary depending on the type of fertilizer applied. Studies have indicated that the use of organic fertilizers can augment the dry matter content of tubers, as evidenced by research on the Spunta variety. Additionally, another investigation highlighted the significant influence of genotype-fertilization interactions on the dry weight of both tubers and foliage [47]. The dry matter content of tubers holds considerable importance in determining the intended use of the product [48]. Tubers with a lower dry matter content (around 18%–20%) are preferable for cooking purposes, as they are less susceptible to mechanical bruising [49]. Conversely, tubers with a higher dry matter content (>20%) are better suited for processing. Thus, alongside selecting an appropriate potato variety, adjusting the fertilization regimen can serve as a cost-effective means to enhance the final product's quality by modulating the dry matter content of the tubers [50]. An increase in nitrogen dosage resulted in a consistent rise in nitrogen concentration in the Atlantic-MG and Agata-BA varieties. However, for Agata-MG, nitrogen rates exceeding 149 kg ha-1 led to a decline in nitrogen concentration. Notably, the Atlantic-MG variety exhibited the least sensitivity to nitrogen dosage variations concerning foliar nutrient concentrations. Specifically, changes in nitrogen dosage did not affect the levels of magnesium, iron, copper, zinc, and boron, maintaining levels within the range of 67–80, 254.2–335–4973, 65.7–76, and 17–21.2 mg kg1 of dry matter, respectively [51]. At lower nitrogen rates (0 and 30 kg ha-1), phosphorus and potassium concentrations in Atlantic-MG fell below the recommended levels by [52]. The highest concentrations of phosphorus and potassium (3.6 and 49 g kg-1, respectively) were observed at nitrogen rates of 202 and 259.5 kg ha-1 in Atlantic-MG. Conversely, in Agata-BA, peak concentrations of phosphorus and potassium (3.9 and 37.3 g kg-1, respectively) were recorded at nitrogen rates of 142.5 and 149.5 kg ha-1. All other essential nutrients met the potato's requirements, with adequate nitrogen levels naturally present in the soil without the need for additional fertilizer, indicating sufficient nourishment provided by the soil for the cultivar [53] The combination of nutrients applied and naturally present in the soil proved adequate to achieve high yields without the need for additional nitrogen application, surpassing the national average yield of 30.5 t ha-1 by 7.8%, 53%, and 15.6% for Atlantic-MG, Agata-MG, and Agata-BA, respectively [54]. The interaction between potato genotypes and nitrogen levels significantly influenced nitrogen content in both plants and tubers. The highest nitrogen content in plants (1.51%) and tubers (0.44%) was observed in AICRP-P-39 with 240 kg N/ha (V1N4) in both years and overall data. Conversely, the lowest nitrogen content in plants (0.70%) and tubers (0.15%) was recorded in V3 N1 across both years and overall data. This indicates that higher nitrogen application to the soil leads to increased nitrogen uptake, resulting in higher nitrogen content in plants and tubers. These findings are consistent with those reported by [55].

Conclusion:

Conclusion From Site-I:

- Different genotypes responded in different ways to the different soil chemical properties, i.e., EC was increased by X4 while reduced by the X7 genotype. Similarly, pH increased with the X7 genotype and was lowered by the X5 genotype.
- Soil fertility is a response variable; the maximum P, K, and organic matter were found in genotype X8, while the maximum mineral nitrogen was found in genotype X3.
- The maximum lime content was found in X4, while the minimum was found in X3.

The Conclusion from Site II

- Different nitrogen levels and genotypes have behaved differently on soil EC. The maximum EC was recorded at 250 kg ha1 of N, while the minimum was recorded at 50 kg ha1, while the response of the genotype and nitrogen level on the EC is different from the site-I X3, X4, and X5, which give the same and highest values.
- The soil pH is in an increasing trend with increasing N levels, while the effect of genotype on nitrogen levels on pH X5 gives the maximum value.
- The phosphorus and potassium give the same response to genotype; the maximum values of both are observed in the X7, while the maximum P was observed in the plot receiving 50 kg ha1, while the maximum k was observed in the plot receiving 150 kg ha1.
- Minerals N, OM, and lime give the maximum value to genotype X4. Response to N fertilizer is the same in OM, and Mineral N obtained the maximum value at 150 kg ha1, while phosphorus gave the maximum value at 50 kg ha1.

Limitations and Recommendations:

Despite providing valuable information regarding the impact of potato genotypes and nitrogen levels on soil health, the study is limited by its particular site and experimental design. Future studies should expand a much broader spectrum of agroecological zones and other variables such as irrigation and crop rotation. Moreover, longer-duration studies are needed to measure the effects of various nitrogen management strategies on productivity and soil fertility. It is recommended to reduce the nitrogen application rates based on the results of soil tests and the nutrients needed for the crop to reduce environmental pollution and maximize crop yield.

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