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Impact of Soil Factors on the Yield and Agronomic Traits of *Hemerocallis citrina Baroni* in the Agro-Pastoral Ecotone of Northern China

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Abstract: The ecologically fragile agro-pastoral ecotone in northern China is characterized by relatively poor arable land quality. Yunzhou District in Datong City, which is situated within this transitional zone, boasts over 600 years of *Hemerocallis citrina Baroni* cultivation. Exploring the effects of soil physicochemical properties on daylily yield and related agronomic traits is essential for enhancing the ecological and economic value of dominant crops in ecologically fragile areas. Therefore, in this study, we focused on the daylily, a characteristic cash crop that is grown in the agro-pastoral ecotone in Yunzhou District. Physicochemical property measurement and yield estimation were performed using soil samples collected from 37 sites, with Spearman's correlation analysis, one-way analysis of variance with multiple comparisons, path analysis, and stepwise regression analysis used to analyze the generated data. The results showed the following: (1) The pathway analysis of daylily yield with each agronomic trait showed that the BN and PH directly affected the yield of daylily with direct pathway coefficients of 0.844 and 0.7, respectively, whereas the SN indirectly affected the yield of daylily through the BD and PH, with indirect pathway coefficients of 0.827 and 0.566, respectively. (2) A total of four principal components were extracted for the soil factors, of which SMC, ST and BD had large loadings on PC1; OM, TN and pH had large loadings on PC2; AK had large loadings on PC3; and AP had large loadings on PC4. (3) From the principal component regression and stepwise regression, it can be seen that SMC is the most critical factor affecting the yield of daylily, as well as the related agronomic traits, and the results also show that yield prediction was affected by OM, ST, and AK, while BN was influenced by OM and ST, and SN and PH were influenced by AP. Comparing the goodness of fit and significance of the two models, it can be concluded that the stepwise regression model is the optimal model for this study.

Keywords: agro-pastoral ecotone; daylily; soil factors; yield; agronomic traits

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1. Introduction

The agro-pastoral ecotone in northern China is situated at the junction between agricultural and pastoral lands and represents a unique and significant transitional interface [1], with an annual precipitation ranging between 300 and 400 mm, thus being categorized as a semi-arid to arid region [2]. The natural conditions within this transitional zone, such as the climate, biological processes, and the soil, together with human production, living mode, and land use methods in the area, have led to an unstable ecological structure, poor disturbance resistance, and a fragile environment [3]. Yunzhou District, located in the middle of this agro-pastoral ecotone, boasts a history of more than 600 years of daylily (*Hemerocallis citrina Baroni*) cultivation, rendering it the largest area of long yellow daylily production in China [4]. Daylily, which is unique to China, belongs to the Hemerocallis genus of the Asphodelaceae family and is a perennial vegetable crop that possesses high nutritional value [5]. Daylily is mainly propagated by dividing clumps into seedlings, which are productive for 2 to 5 years after dividing, after which the yield decreases due to excessive tillering of the seedlings and the depression of the clumps. After 5 to 7 years of growth, new seedlings are obtained by dividing clumps, and then planted in clusters of two to three plants in the new field. The flowering period of daylily is from late June to late July every year, and it is usually harvested around the end of the summer, with a harvesting period of about 40 d. The edible part of daylily is the flower buds, which are usually processed into dried vegetables and eaten, and they have a high nutritional value, while they can be used as a tonic for pregnant women and the elderly and the infirm [6].

Daylily also has both economic and ecological value, is adapted to a wide range of conditions and is resistant to poor soils and drought. This perennial herbaceous plant has a well-developed root system that renders it beneficial as a windbreak, while also fixing the sandy soil and enhancing soil and water conservation [7]. The abundant sunlight and significant diurnal temperature difference in Yunzhou District is beneficial to the growth of daylily, which is golden in color, with large buds, thick flesh, rich nutrition, and a strong fragrance, ranking it highest nationwide for its appearance and edible qualities. Daylily has thus become Datong's first nationally protected geographical indication product [6]. With cultivation currently covering a total of 17,300 ha, daylily production has become an important industry that enhances the income of many local farmers [8].

Clarifying the yield characteristics of daylily and identifying the main factors affecting yield are crucial for improving the quality, enhancing the yield, and promoting the healthy and sustainable development of this plant as a cultivated crop [9]. In addition, studying the factors that affect crop yield has become an area of interest in agronomy and related disciplines [10]. Soil factors, as critical components of the soil environment, not only reflect the fertility level of a soil but also influence the relationship between plants and the soil. Soil nutrient content is crucial for the quality and yield of crops during growth, with varying soil fertility conditions leading to differing crop yields and qualities. Several studies have examined the effect of fertilization on growth. Jat et al. showed that the foliar application of urea (2%) during the flowering and pod development stages of broad beans significantly increased the nitrogen, phosphorus, and potassium contents of seeds and stems [11], while Brhane Hagos suggested that splitting potassium fertilization considerably affects wheat yield and its components as compared to the provision of a single full dose [12]. Beltrán-Paz Ofelia demonstrated that combining urea with organic fertilizers increased oat yields by 15% as compared to synthetic fertilizers alone [13], and field experiments conducted by Yan Xiaojun revealed considerable differences in wheat yield and phosphorus fertilizer efficiency under different phosphorus treatments [14]. Wu Yichao examined the effects of soil pH on the active component content of Polygonum multiflorum and observed that pH stress notably affects the normal growth, physiological functions, and photosynthetic indices of this plant [15].

Substantial research has also been conducted on the daylily within China. Li Xiaozhen et al. [16] analyzed meteorological conditions in the main daylily production areas of Northern Shanxi, and noted a trend of increasing temperature alongside a decrease in precipitation, hail days, and sunlight hours during the primary growth period. Chen Zhenhao et al. [17] examined the climate and major meteorological disasters affecting daylily cultivation in Dehua. Gao Zhihui [18] compared the nutritional quality of dried daylily from Qidong County, Hunan Province, Quxian County, Sichuan Province, Shaodong County, Hunan Province, Datong County, Shanxi Province, and Qingyang County, Gansu Province and found that the daylily samples from Datong County had the highest soluble protein content. Zhou Lingling et al. [19] analyzed the growth characteristics and nutritional quality of different daylily varieties in Northern Jiangsu and identified the best varieties for the regional conditions, while Zhang Bo et al. [20] compared the quality characteristics of daylily with other vegetables in Qingyang, promoting the development of the daylily industry in the region. Other studies have examined the association between various daylily traits and yield [21] and have explored the effects of different drip irrigation and water-fertilizer conditions on daylily yield and growth [22,23].

However, the factors that influence daylily yield and agronomic traits in the central part of the northern agro-pastoral ecotone remain unclear, hindering the development of effective cultivation and management strategies for the regional daylily industry. Based on this, this study intends to analyze the effects of different soil physicochemical properties on the yield and related agronomic traits of daylily by investigating the main production areas of daylily in Datong, so as to provide reference data for the research on the yield and traits of daylily in this agro-pastoral ecotone with a view to improving the economic and ecological value of daylily in the study area.

2. Materials and Methods

2.1. Study Area

The experimental site is located in the middle of the agro-pastoral ecotone in Yunzhou District, Datong City, Shanxi Province, northern China (Figure 1). Yunzhou District has an average annual temperature of 6.4 °C, an average annual sunshine duration of 2825 h, and average annual precipitation of 395 mm. The soil is primarily chestnut soil, with surface water mainly sourced from the Sanggan River and Yu River. Agricultural crops that are grown in the area in addition to daylily include corn, sorghum, and potatoes.

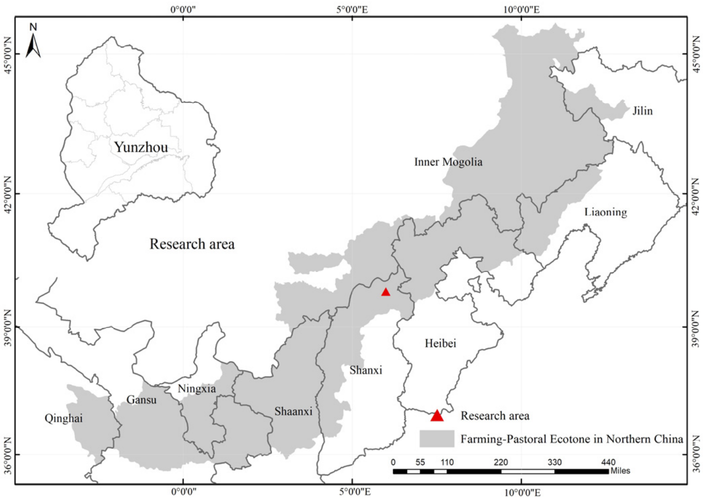

Figure 1. Geographical location of the research area.

2.2. Plot Survey and Sampling Methods

Surveying was conducted across 197 villages in Yunzhou District, with the focus primarily being on the cultivation duration, yield, and soil fertility conditions of daylily. Fields in which daylilies were grown in contiguous plots 4–5 years prior to the study were selected for sampling, resulting in a total of 37 sampling sites (Figure 2) within the study area. Surface soil samples were collected from a depth of 20 cm at each site using a soil auger according to the five-point sampling method. The cutting-ring method was used to obtain undisturbed soil samples for the determination of soil bulk density (BD) and soil moisture content (SMC), while the determination of soil texture (ST) was conducted via hand measurement [24]. We took a small sample of soil (slightly larger than an abacus bead), picked out stone particles, dead leaves, and insect residues by hand, added an appropriate amount of water, mixed it up, kneaded it back and forth in the palm of the hand, kneaded it into the order of balls, strips, and rings, and then finally flattened the ring, observing the condition of each link to make a comprehensive judgement. Sandy soil cannot be kneaded into strips or balls; sandy loam can be kneaded into a ball, but cannot be rolled into strips and easily cracks into small segments; light loam can be rolled into strips, but easily breaks when lifted; medium loam can be rolled into a ball and strips, and breaks when crushed; heavy loam can be rolled into a ball and strips and can be curved into a ring, and when squashed it displays large cracks; and clay can be rolled into a ball and strips, its thin strips can be curved into a ring, and when squashed it does not crack.

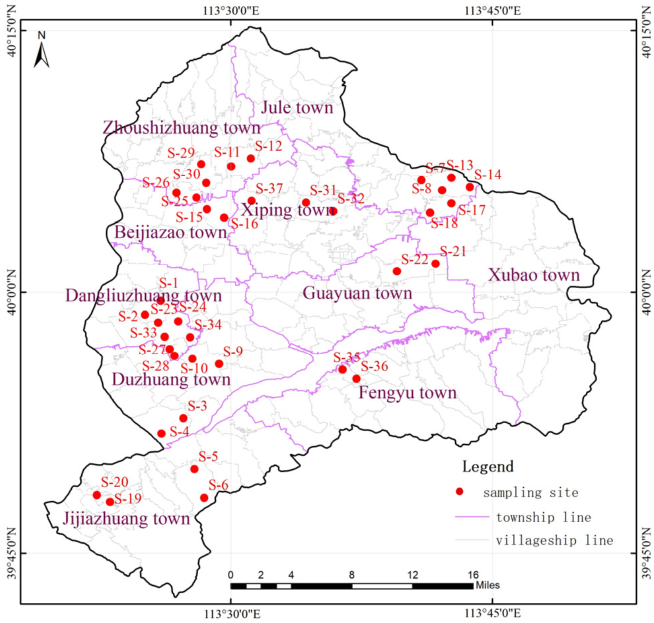

Figure 2. Sample points of the research area.

For analysis, approximately 1 kg of a collected sample was divided using the quartering procedure, air-dried, ground, and sieved to analyze soil pH, soil organic matter (OM), and other indicators. Soil pH was determined via potentiometry, OM was determined via the potassium dichromate volumetric method, total nitrogen (TN) was determined using the Kjeldahl method, available phosphate (AP) was determined using the double acid extraction-molybdenum antimony colorimetry method, and rapidly available potassium (AK) was determined using the ammonium acetate extraction-flame photometry method.

2.3. Daylily Trait Measurement and Yield Estimation

For plant analysis, 10 healthy daylily plants were randomly picked from each plot during the harvest period in mid to late July, and the scape number (SN), plant height (PH), and bud number (BN) of each plant were recorded. The total weight of the buds was used to calculate the average fresh weight. The row spacing and plant spacing of daylilies in the plot were also measured to calculate the number of daylily plants per hectare, and the yield per hectare was estimated by multiplying the number of plants per hectare by the average BN per plant and the average fresh weight per bud.

2.4. Data Processing and Analysis

The experimental data were processed using Microsoft Excel 2016 and the SPSS 25 statistical software. Graphs were drawn using Origin 2021. The average daylily yield, related agronomic traits, and soil factors were then calculated together with the standard deviations, and the coefficient of variation (CV) was obtained as the standard deviation/average value × 100% (Table 1) Through Spearman's rank correlation analysis, the correlation between the yield of yellow flowers and various traits with soil physicochemical properties was examined. Path analysis was then employed to explore the relationship between yield and agronomic traits. Subsequently, principal component analysis (PCA) was used to reduce multiple variables into a few principal components. The regression models for the yield of yellow flowers and agronomic traits with soil factors were constructed using principal component regression and multiple linear regression. The results of the two regression models were compared to determine the most suitable regression method.

Table 1. Variation features of yield and related characters of daylily and soil factors.

Index		Max	Min	Mean ± SD	CV/%
Daylily	Yield (kg/hm^2)	25,569	4419	13,941 ± 6592	47.28
	Bud number	207	32	102 ± 50	48.98
	Scape number	18	5	10 ± 3	34.09
	Plant height (cm)	133	95	112 ± 11	9.95
Soil factors	SMC (%)	16.53	5.91	11.66 ± 2.77	23.76
	BD (g/cm^3)	1.48	0.81	1.17 ± 0.29	15.93
	OM (g/kg)	18.57	5.16	8.44 ± 3.47	41.15
	AP (mg/kg)	28.23	7.14	15.47 ± 6.11	39.50
	AK (mg/kg)	268.03	57.59	138.20 ± 56.27	40.71
	TN (g/kg)	1.76	0.57	0.83 ± 0.23	28.19
	pH	8.85	8.32	8.54 ± 0.13	1.54

Abbreviations: SMC—soil moisture content; BD—bulk density; OM—soil organic matter; AP—available phosphate; AK—rapidly available potassium; TN—total nitrogen.

3. Results

3.1. Path Analysis of Daylily Yield and Agronomic Traits

Daylily's agronomic traits, including BN, SN, and PH, impact its yield to a certain extent, either directly or indirectly through other factors. Path analysis was thus conducted to elucidate the association between yield and agronomic traits, with both direct and indirect effects estimated [25,26].

Path coefficients are standardized partial regression coefficients that represent the directional correlation between independent and dependent variables and are situated between regression coefficients and simple correlation coefficients in terms of statistical analysis. Their primary significance lies in their ability to illustrate how independent variables directly or indirectly affect the dependent variable. In this case, path analysis was conducted using BN (A_1), SN (A_2), and PH (A_3) as independent agronomic traits and yield (Y) as the dependent variable. The results are shown in Table 2.

Table 2. Path analysis between bud number, scape number, plant height and yield.

Characters	Correlation Coefficient	Direct Path Coefficients	Indirect Path Coefficient		
			A_1-Y	A_2-Y	A_3-Y
A_1	0.963	0.844		−0.136	0.565
A_2	0.940	−0.139	0.827		0.566
A_3	0.799	0.700	0.681	−0.112	

Path analysis revealed high significance for the correlation coefficients of BN, SN, and PH with respect to yield, although considerable variation was observed in the path coefficients. The most significant direct path coefficient of 0.844 was obtained for BN (A_1), while indirect path coefficients of −0.136 and 0.565 were obtained for SN and PH, respectively. The substantial direct contribution of BN indicates that it directly affects yield. In contrast, SN affected yield mainly through its effect on BN, with an indirect path coefficient of 0.827 and a direct path coefficient of −0.139, while PH showed a direct path coefficient of 0.7, which is greater than the obtained indirect effect for this attribute.

3.2. Correlation of Daylily Yield and Various Traits with Soil Factors

As shown in Figure 3, soil moisture content, soil texture, SOM, TN, BN, SN, and PH were all significantly positively correlated with yield ($p < 0.01$), while soil bulk density and soil pH showed significant negative correlations ($p < 0.01$). Soil moisture content showed significant positive correlations with soil texture, SOM, TN, BN, SN, and PH ($p < 0.01$), significant negative correlations with soil bulk density and soil pH ($p < 0.01$), and a significant positive correlation with AK ($p < 0.05$). Soil bulk density was significantly negatively correlated with soil texture, SOM, TN, BN, SN, and PH ($p < 0.01$), and significantly positively correlated with soil pH ($p < 0.01$). Soil texture was significantly positively correlated with SOM, TN, BN, SN, and PH ($p < 0.01$) and significantly negatively correlated with soil pH ($p < 0.05$). SOM was significantly positively correlated with TN, BN, SN, and PH ($p < 0.01$) and significantly negatively correlated with soil pH ($p < 0.01$). AP was significantly positively correlated with AK ($p < 0.01$). TN was significantly negatively correlated with soil pH ($p < 0.01$) and significantly positively correlated with BN, SN, and PH ($p < 0.01$). Soil pH was significantly negatively correlated with BN, SN, and PH ($p < 0.01$). These correlations indicate that soil physicochemical properties do not independently affect daylily yield and that the interaction among the various factors is complex.

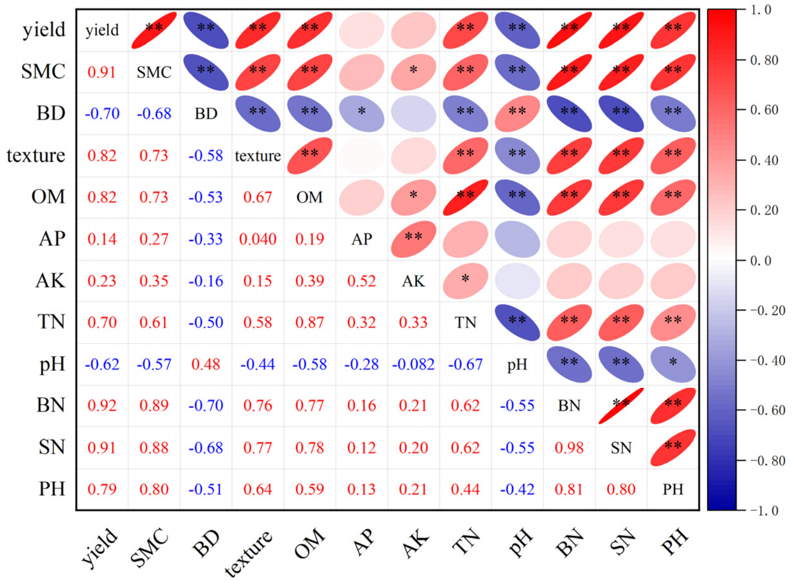

Figure 3. Correlation plot of each indicator and soil factor in daylily (* and ** indicate that the correlations are significant at $p < 0.05$ and $p < 0.01$, respectively. Abbreviations: BN—bud number; SN—scape number; PH—plant height; SMC—soil moisture content; BD—bulk density; OM—soil organic matter; AP—available phosphate; AK—rapidly available potassium; TN—total nitrogen; pH—pondus hydrogenii).

3.3. Principal Component Analysis of Soil Factors

Owing to the robust associations among all soil factors, the analysis ought to include dimensionality reduction. Principal component analysis was performed after standardizing the raw data for the soil factors. Principal component analysis is a statistical technique that, by finding correlations between variables, extracting as much information as possible, and reducing dimensionality using dimensionality reduction, reduces many variables into a small number of composite variable components [27,28]. The data may be appropriate for principal component analysis, as shown by the KMO test coefficient of 0.742 > 0.5 and the Bartlett's spherical test of $p < 0.05$. The cumulative variance contribution rate was 72.11% < 85% for the two principal components with eigenvalues greater than 1, and 89.573% > 85% for the four principal components. Therefore, the first four principal components were chosen to better represent the variation information of the soil factors.

The component matrices are displayed in Table 3 following Kaiser's normalized maximum variance method of rotation. The results are easier to read and the rotated coordinate system can better capture the underlying structure of the data. Table 3 illustrates this, and shows that the physical properties of the soil are represented by PC1, which has large positive loadings for SMC and ST; large negative loadings for BD and OM; large positive loadings for pH and TN; and large positive loadings for AK and AP on PC3 and PC4, respectively. The double-labelled plots (Figure 4) show the magnitude of loadings on PC1 and PC2 for all variables (four daylily traits and eight soil factors) and sampling points.

Table 3. The component matrix after the rotation.

Soil Factors	Ingredient			
	1	2	3	4
SMC	0.748	0.418	0.251	0.152
BD	−0.882	−0.229	0.043	−0.196
ST	0.825	0.353	0.115	−0.165
OM	0.463	0.76	0.371	−0.08
AP	0.055	0.129	0.32	0.897
AK	0.108	0.082	0.899	0.317
TN	0.334	0.882	0.162	0.073
pH	−0.305	−0.783	0.23	−0.345

Note: Extraction method: PCA; rotation method: Kaiser's normalized maximum variance method of rotation. Rotation converges after the 8th iteration.

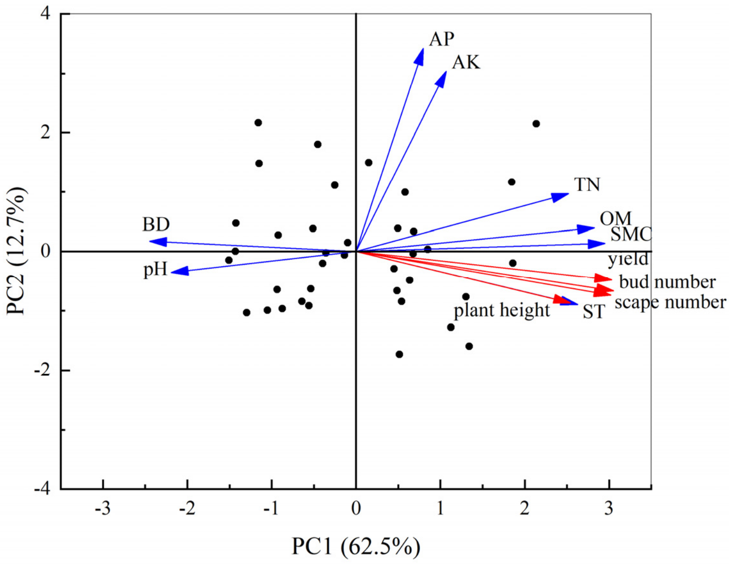

Figure 4. Biplot of daylily traits and soil factors (the blue vectors in the figure represent soil factors, the red vectors represent daylily traits, and each point represents a soil sampling point).

3.4. Regression Analysis of Daylily Yield and Various Indexes and Soil Factors

We considered using the principal component regression model and the stepwise regression model for optimization, and we compared the two models' results. The preliminary results of the analysis of each soil indicator show that the covariance statistic VIF of some parameters was greater than 10, indicating that there was a problem of multiple covariance in the characteristic indicators. If multiple regression modelling was used at this time, it would lead to unstable analysis results, and even the sign of the regression coefficients would be completely opposite to the actual situation.

3.4.1. Effects of Daylily's Agronomic Traits on Yield

Table 4 is the component score coefficient matrix, through which all principal components are represented as linear combinations of individual variables. X_1–X_8 represent the standardized independent variables, including the soil water content (X_1), soil bulk density (X_2), soil texture (X_3), organic matter (X_4), effective phosphorus (X_5), quick potassium (X_6), total nitrogen (X_7), and pH (X_8). The expressions of the four principal component variable sets F1, F2, F3 and F4 are as follows:

$$F1 = 0.357X_1 - 0.628X_2 + 0.46X_3 - 0.121X_4 - 0.019X_5 - 0.064X_6 - 0.264X_7 + 0.157X_8 \quad (1)$$

$$F2 = -0.107X_1 + 0.354X_2 - 0.148X_3 + 0.412X_4 - 0.095X_5 - 0.087X_6 + 0.58X_7 - 0.475X_8 \quad (2)$$

$$F3 = 0.083X_1 + 0.259X_2 + 0.058X_3 + 0.331X_4 - 0.032X_5 + 0.816X_6 + 0.059X_7 + 0.463X_8 \quad (3)$$

$$F4 = 0.04X_1 - 0.251X_2 - 0.344X_3 - 0.35X_4 + 0.857X_5 - 0.016X_6 - 0.124X_7 - 0.355X_8 \quad (4)$$

Table 4. The component score coefficient matrix.

Soil Factors	**Ingredient**			
	1	**2**	**3**	**4**
X1	0.357	−0.107	0.083	0.04
X2	−0.628	0.354	0.259	−0.251
X3	0.46	−0.148	0.058	−0.244
X4	−0.121	0.412	0.331	−0.35
X5	−0.019	−0.095	−0.032	0.857
X6	−0.064	−0.087	0.816	−0.016
X7	−0.264	0.58	0.059	−0.124
X8	0.157	−0.475	0.463	−0.355

Note: Extraction method: PCA; rotation method: Kaiser's normalized maximum variance method of rotation.

F1, F2, F3, and F4 were used as independent variables, and the daylily yield (y1), bud count (y2), scape count (y3), and plant height (y4) were, respectively, the dependent variables as shown in the table below.

Adding the equations in Table 5 into Equations (1)–(4), the resulting principal component regression equation is:

$$y1 = 0.450 + 0.068X_1 - 0.074X_2 + 0.084X_3 - 0.056X_4 - 0.020X_5 + 0.007X_6 + 0.039X_7 - 0.024X_8 \quad (5)$$

$$y2 = 0.401 + 0.059X_1 - 0.055X_2 + 0.077X_3 + 0.062X_4 - 0.035X_5 + 0.010X_6 + 0.044X_7 - 0.018X_8 \quad (6)$$

$$y3 = 0.362 + 0.054X_1 - 0.052X_2 + 0.074X_3 + 0.055X_4 - 0.039X_5 + 0.009X_6 + 0.035X_7 - 0.008X_8 \quad (7)$$

$$y4 = 0.459 + 0.054X_1 - 0.050X_2 + 0.074X_3 + 0.051X_4 - 0.039X_5 + 0.023X_6 + 0.024X_7 + 0.010X_8 \quad (8)$$

where the independent variables X_1–X_8 and the dependent variables y1–y4 are all the normalized values.

The adjusted R^2 in the regression model is the modified value of R^2, which avoids the issue of the model changing due to the addition of predictive factors. It reflects the overall goodness of fit of the regression model, which is discussed in [29]. By conducting a significance test on the regression equation, the obtained F values are all greater than the critical value F ($\alpha = 0.01$), indicating a very close relationship between the selected soil factors and the yellow flower index. The significance of the principal component regression equation is extremely high.

3.4.2. Stepwise Regression Analysis

Multiple linear regression models were constructed via stepwise regression. X_1–X_8 represent the standardized independent variables, including soil water content (X_1), soil bulk density (X_2), soil texture (X_3), organic matter (X_4), effective phosphorus (X_5), quick potassium (X_6), total nitrogen (X_7), and pH (X_8), while the daylily yield (y1), bud count (y2), scape count (y3), and plant height (y4) are the dependent variables. The goodness of fit and significance of the regression model were tested to obtain the final regression equation, as shown in Table 6.

Table 5. Principal component regression analysis of daylily yield, bud, scape, and plant height with soil factors.

Index	Equation	Standardization Coefficient B	R^2	Adjust R^2	F
Yield	y1 = 0.450 + 0.230 F1 + 0.168 F2 + 0.045 F3 + 0.002 F4	B_{F1} = 0.727 B_{F2} = 0.532 B_{F3} = 0.141 B_{F4} = 0.008	0.831	0.810	39.316 **
bud number	y2 = 0.401 + 0.204 F1 + 0.161 F2 + 0.045 F3 − 0.017 F4	B_{F1} = 0.716 B_{F2} = 0.564 B_{F3} = 0.159 B_{F4} = −0.061	0.860	0.842	49.036 **
scape number	y3 = 0.362 + 0.185 F1 + 0.135 F2 + 0.040 F3 − 0.025 F4	B_{F1} = 0.725 B_{F2} = 0.529 B_{F3} = 0.156 B_{F4} = −0.099	0.840	0.821	42.156 **
plant height	y4 = 0.459 + 0.175 F1 + 0.110 F2 + 0.053 F3 − 0.028 F4	B_{F1} = 0.594 B_{F2} = 0.375 B_{F3} = 0.179 B_{F4} = −0.094	0.534	0.476	9.166 **

Note: The dependent variables y1, y2, y3, and y4 are all standardized values, and ** represents extreme significance at $p < 0.01$. Column "B" presents the influence coefficient of the independent variables in the equation.

Table 6. Stepwise regression analysis of daylily yield, bud, scape, and plant height with soil factors.

Index	Equation	Standardization Coefficient B	R^2	Adjust R^2	F
yield	$y1 = -47.422 + 6.111 X_1 + 35.881 X_3 + 2.565 X_4 - 0.065 X_6$	B_{X1} = 0.570 B_{X3} = 0.225 B_{X4} = 0.300 B_{X6} = −0.123	0.921	0.911	93.087 **
bud number	$y2 = -85.408 + 9.117 X_1 + 4.076 X_4 + 65.646 X_3$	B_{X1} = 0.505 B_{X4} = 0.283 B_{X3} = 0.245	0.876	0.864	77.400 **
scape number	$y3 = -1.759 + 0.682 X_1 + 3.625 X_3 + 0.25 X_4 - 0.087 X_5$	B_{X1} = 0.582 B_{X3} = 0.208 B_{X4} = 0.267 B_{X5} = −0.164	0.880	0.865	58.716 **
plant height	$y4 = 78.942 + 3.463 X_1 - 0.384 X_5$	B_{X1} = 0.858 B_{X5} = −0.21	0.675	0.656	35.385 **

Note: The independent variables X_1–X_8 and the dependent variables y1–y4 are the raw data values and ** represents extreme significance at $p < 0.01$. Column "B" presents the influence coefficient of the independent variables in the equation.

3.4.3. Model Comparison

From Tables 5 and 6, it can be seen that both the principal component regression and stepwise regression models constructed for the yield and agronomic traits of yellow-flowered vegetables have strong significance with soil factors. The goodness of fit and significance of the latter are slightly higher. Further comparison of the regression equations constructed by the two models reveals the following:

The yield and soil factor model constructed based on principal component regression shows that the ST (B_{X3} = 0.084) has the largest impact coefficient on soil factors, followed by BD (B_{X2} = −0.074), SMC (B_{X1} = 0.068), and OM (B_{X4} = 0.056). On the other hand, the yield and soil factor model constructed based on stepwise regression includes SMC (B_{X1} = 0.570), ST (B_{X3} = 0.225), OM (B_{X4} = 0.300), and AK (B_{X6} = −0.123) as the soil factors involved in the modeling process. This indicates that SMC and ST have a greater impact on yield.

The BN and soil factor model constructed based on principal component regression shows that the ST (B_{X3} = 0.077) has the largest impact coefficient on soil factors, followed by OM (B_{X4} = 0.062), SMC (B_{X1} = 0.059), and BD (B_{X2} = −0.055). On the other hand, the yield and soil factor model constructed based on stepwise regression includes SMC (B_{X1} = 0.505), OMC (B_{X4} = 0.283), and ST (B_{X3} = 0.245) as the soil factors involved in the modeling process. This indicates that SMC and OM have a greater impact on BN.

The SN and soil factor model constructed based on principal component regression shows that the ST (B_{X3} = 0.074) has the largest impact coefficient on soil factors, followed by OM (B_{X4} = 0.055), SMC (B_{X1} = 0.054), and BD (B_{X2} = −0.052). On the other hand, the yield and soil factor model constructed based on stepwise regression includes SMC (B_{X1} = 0.582), ST (B_{X3} = 0.208), OMC (B_{X4} = 0.267), and AP (B_{X5} = −0.164) as the soil factors involved in the modeling process. This indicates that SMC, ST, and OM have a greater impact on SN.

The PH and soil factor model constructed based on principal component regression shows that the ST (B_{X3} = 0.074) has the largest impact coefficient on soil factors, followed by SMC (B_{X1} = 0.054), OM (B_{X4} = 0.051), and BD (B_{X2} = −0.050). On the other hand, the yield and soil factor model constructed based on stepwise regression includes SMC (B_{X1} = 0.858) and AP (B_{X5} = −0.21) as the soil factors involved in the modeling process. This indicates that SMC has a greater impact on PH.

In principal component regression models, including more variables in the regression equation is of guiding significance for optimizing soil fertility research. On the other hand, multiple linear regression models eliminate insignificant independent variables and only select the most significant factors for modeling, resulting in a more concise, intuitive, and accurate model.

4. Discussion

4.1. Interactions between Soil Physiochemical Properties and the Effects on Daylily Yield

Soil fertility is the measure of a soil's capacity to provide the various nutrients that are required for growth and reflects the level of soil productivity, with the composition and content of soil nutrients constituting the fundamental conditions for soil fertility and productivity [30]. Daylily yield is directly related to soil nutrient content, and research into the distribution characteristics of soil nutrients holds significant value for enhancing the yield and quality of daylilies.

Numerous factors influence the yield and growth status of this plant, and this study focused on eight soil factors in the Yunzhou region: soil moisture content, soil bulk density, soil texture, SOM, AP, AK, TN, and pH. Soil moisture content, soil bulk density, and soil texture are physical properties, with soil texture being a stable natural attribute that considerably affects other physicochemical soil and crop growth properties. Sandy soil, with high aeration and loose texture, is beneficial for the deep growth of daylily roots; however, the poor water and nutrient retention capabilities of this type of soil are not conducive to late-stage growth and yield. Dense and poorly aerated clay soils are nutrient-rich; however, the associated lower nutrient absorption efficiency means that the contribution of this soil type to crop growth is moderate at best. Loam, offering a balance between sandy soil and clay, provides moderate permeability and good water and nutrient retention, facilitating both root growth and biomass accumulation, thereby supporting rapid daylily growth. These results align with the findings of Jiao Runxing et al. [31], who found that cotton yield decreased in the order loam > sandy soil > clay. Soil moisture content is a crucial factor affecting daylily growth and bud yield, with different moisture levels leading to different soil pH values and SOM contents, and generally higher soil moisture contents are more conducive to daylily growth and yield. An opposite trend is observed for soil bulk density in terms of yield, because both soil structure and particle distribution affect soil moisture. Moreover, Liu Dong et al. [32] showed that (1) soil pore size distribution is a dominant factor influencing soil moisture characteristics; (2) soil particle size distribution is the dominant factor influencing the soil moisture characteristics of soils with high moisture content, and that soil structure exhibits a high impact on the soil moisture characteristics; and

(3) increasing the initial soil moisture content leads to a decrease in the correlation between soil structure and soil moisture characteristics. Thus, soil texture, soil moisture content, and soil bulk density impact the yield and agronomic traits of daylily both independently and collectively. In the process of daylily planting, loamy soil with a moderate weight and a high water content should be selected, and the soil moisture should be supplemented by irrigation in cases of dry and infertile soil.

The three soil chemical properties, SOM, TN, and pH, were found to be significantly related to daylily yield, with strong mutual correlations. Specifically, both SOM and TN were significantly negatively correlated with pH, indicating that lower pH within a certain range leads to higher SOM and TN contents, resulting in higher yield. This is consistent with the findings of Sun Yiming [33], who studied the variations in soil pH and SOM content under different land uses (dry fields, paddy fields, grasslands, forests, and unused land) over a period of 20 years and observed a sharp decrease in soil pH in northern China and a slight decrease in southern China over this period, with both regions experiencing a notable increase in SOM content. Zainal [34] indicated that applying liquid organic fertilizer to sweetcorn leads to a linear increase in the SOM and TN content, which is consistent with the findings of this study. Furthermore, the results of this study suggest that AP and AK are not the primary factors affecting daylily yield. Notably, the overall AP and AK levels were moderate rather than low in the study area, and significant positive correlation was observed between the two. Therefore, it cannot be ruled out that the interaction of AP and AK may also impact daylily yield. Therefore, in future studies, the growth and yield of daylily under dynamic changes in soil conditions will be continuously monitored to explore the genetic variation in the response of daylily to soil conditions.

4.2. Relationship of Soil Factors to Daylily Yield and Related Agronomic Traits

Path analysis indicated a correlation between yield and the three studied agronomic traits. Ramesh Kumar et al. [35] used correlation and path analysis to study 30 F1 hybrids and six Solanum parents and found that the genotypic correlation coefficients for most traits were higher than their corresponding phenotypic correlation coefficients, with the fruit yield per plant showing a highly significant positive correlation with fruit length and the number of fruits per plant, suggesting that fruit yield can be increased through the selection of yield components. In the present study, BN and PH were observed to directly affect daylily yield, while SN had an indirect effect and occurred mainly through changes in the BN and PH. This finding may be related to row and plant spacing, as both can affect the synthesis and distribution of photosynthetic products, affecting the SN, BN, bud weight, and fruit fullness per plant and ultimately impacting the final yield. In future studies, we plan to explore how different row and plant spacing combinations affect daylily yield by influencing the soil physicochemical properties and related agronomic traits.

Stepwise regression analysis was used to perform linear regression on soil factors vs. daylily yield and related agronomic traits, allowing key soil factors to be identified. Soil moisture content was the most critical factor affecting yield, BN, SN, and PH. Wang Xuchen [36] conducted a water and fertilizer requirement test on daylilies in the arid areas of Ningxia, and observed that under different drip irrigation conditions, the PH, leaf width, stem thickness, flower length, flower thickness, and single-flower fresh weight of daylilies exhibited different performances, with general increases observed under increasing irrigation, which is consistent with the results of this study. Phosphorus is an indispensable nutrient element for crop growth and development, participating in several key life processes and having a significant impact on crop root development. The present study demonstrated that AP is also an important factor affecting SN and PH. Zhang Yingying et al. [37] showed that the application of phosphorus fertilizer significantly affects PH, while Zhang Yangzhu et al. [38] found that potassium fertilizer can promote daylily yield by enhancing its disease and stress resistance, increasing its BN and single-flower fresh weight.

5. Conclusions

In this study, we analyzed the response of daylily yield and related agronomic traits to the soil physicochemical properties in the Yunzhou District of Datong City in the northern China agro-pastoral ecotone. The results indicate that soil physicochemical properties significantly influence both yield and the related agronomic traits ($p < 0.05$), with both being primarily regulated by soil moisture content, SOM content, and soil texture. Stepwise regression analysis further revealed that the content of available phosphorus can be used to effectively predict SN and PH, while that of rapidly available potassium can be used to predict daylily yield. Path analysis of daylily yield and various agronomic traits indicates that BN and PH directly impact daylily yield, while SN indirectly influences daylily yield through its effects on BN and PH. The robust environmental adaptability of daylilies and their ecological value in acting as a windbreak, sand fixation, and soil moisture retention are expected to increase as global climate change, regional water scarcity, and soil degradation continue.

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