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Research article

STUDY THE RELATIONSHIPS BETWEEN YIELD AND YIELD COMPONENTS OF POTATO VARIETIES USING CORRELATION ANALYSIS AND REGRESSION ANALYSIS AND CAUSALITY

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ABSTRACT: In order to evaluate the correlation between attributes and their analysis to causal relationships in the potato crop, an experiment was performed in Agriculture and Natural Resources Research Station of Ardabil on six genotypes in a split plot test based on completely randomized blocks with three replications. In the statistical analysis of this study, 21 traits were studied and analyzed. To perform this experiment, water stress was applied by increasing the irrigation interval during the growth period of the plant. The irrigation period factor with three levels of irrigation without stress (irrigation every 6 days), the average stress (irrigation every 12 days) and severe stress (irrigation every 18 days) in the main plots and the potato varieties factor in 6 levels in the subplots were evaluated. ANOVA results showed that regarding different levels of irrigation and the studied varieties, apart from the traits of the number of days until tuber developing and the percentage of green plants, there were significant differences in all traits. The Sornad and Agria cultivars had the highest average in tuber yield, respectively, with 28.78 tons per ha and 28.28 tons per ha, and the Draga cultivar produced the lowest average tuber yield with 24.41 tons per acre. Potato cultivars with different irrigation periods showed mutual effects in terms of plant height, number of main stem, number of tubers per plant, tuber weight per plant, tuber yield, edible tubers percentage. This showed that the difference in cultivars has not been the same in different irrigation periods. The tuber yield had a significant positive correlation with leaf area index, edible tubers percentage, plant cover percentage, plant height, main stem diameter, weight of tubers per plant, number of tubers per plant and the percentage of 45-55 mm tubers, while it had a significant negative correlation with the percentage of 28-35 mm tubers, the percentage of 35-45 mm tubers, storage loss percentage and the percentage of non-seeding tubers. In fitting the best multivariate regression model by descending method for all studied traits, by inclusion the traits of green plant percentage, tubers weight per plant and the percentage of tubers between 35-45 mm, the best model was fitted. These were the most important traits as the independent variable to develop the tuber yield as the dependent variable.
Keywords: Potato, Correlation, Descending Regression, Path Coefficients, Yield

INTRODUCTION

Potato has different and much species that from its various species, there are agricultural species called *SolanumTubberesum* that are consumed by humans [1]. This product has a special importance for developing countries due to increasing potential in area unit and time unit and has more nutritive value to keep and hold increasing undernourished and hungry population. After milk, it is the first product that can take into account as a complete food. Except fat, it has all minerals, amine acids and starch and is a good source for required sugar and is full of energy [2]. Due to importance of potato in production of food, in comparison with 20 major foods, based on wet weight, it has allocated sixth rank in developing countries and fourth in developed countries of the world .Annual production of it in Iran with more than 4.5 million tons has allocated third rank after wheat and rice to itself [3]. Potato is the most important planting in order to produce food all around the world. This product is planting in more than 160 countries in the world. It is one of the tuber products which is rich in carbohydrate and in the world is an important diet, and because of its high yield per hectare, it has attracted a lot of attention. So that in comparison with grains it produces the same amount of protein and nearly twice crabs per hectare. The tuber of this plant is economically valuable and is always utilized in animal or human food supply and starch production [4]. Since most points of our country are located in arid and semiarid regions and have limited water resources, water is the first and the most important factor of limitation in increase of agricultural products particularly in potato. It is also predicted that climate changes will heat the air in future and as a result, water need if plants increases and use of water resources is limited more [5].

Water shortage is one of the most common types of stress in potato agriculture [6] and is one of the important factors of decreasing yield. Since potato is sensitive to water stress (7; 8 and 9). Provision of enough irrigation water is regarded as one of the important ways of increasing quality and quantity of potato. Based on research by Harris [9] and Struik and Voorst [10], soil water content should not be less than 50% of maximum accessible water in the root to obtain high yield in potato. Provision of enough water after formation of tuber increases tuber size per plant (8). Water stress during germination decreases yield (11; 12 and 13) and number of tuber in plant of some cultivars (10). Intensive drought stress along with high temperature particularly in early tuber growth period when soil is not covered with branch and leaf can cause secondary growth [14]. Drought stress reduces area of leaf and average weight of tuber [15]. Researches by Shock *et al*, (16) show that if plants are exposed to hydraulic stress condition before tuberization, their quality will be improved at time of harvesting and low tubers with end of dark brown stem will be observed.

In general, there is a poor correlation between one thousand seeds weight and the plant yield. Although there is genetic diversity for one thousand seeds weight, but such a selection for high one thousand seeds weight has a negative effect on other yield components.

MATERIALS AND METHODS

Location of testing

The study was carried out in Ardabil Agricultural Research Station located at Alaroq a village at 12 km south of Ardabil. The location was a semi-arid and cold climate that in winter is often below zero. Region has a long dry season, especially in summer. Altitude is reported 1350 m, latitude and longitude, respectively 20' 48 ° and 15' 38°, the mean minimum, and maximum temperatures were 1.98, 15.8 and 21.58 ° C and the precipitation annual average is 310.9 mm.

Herbal material

In this study, six potato varieties with medium to late maturity were used. Agria and Draga as the control varieties of the region with Diament, Cosima, Sernad and Asterix, which had nearly the same growth period were evaluated in this experiment. The varieties l was prepared from agricultural research station of Ardabil.

How to perform the experiment

This experiment aimed at evaluating the indicators of cultivars tolerance to drought was performed in the form of split plots based on completely randomized blocks in three replicates. In this study, the main factor of irrigation period (A: every 6 days, A2: every 12 days and A3: every 18 days) and the sub-factor of potato varieties in six levels were placed in the main plots and sub-plots, respectively. Planting was done in a ground that had been in fallow in the previous year. To prepare the intended ground, it was deep plowed in the autumn, and the phosphorus fertilizer as 110 kg per ha and potash fertilizer as 55 kg per hectare were mixed with the soil. In April, after superficial plowing and land flattening, the furrows were created by Furrower apparatus, and simultaneously with planting on May 14, half the required nitrogen fertilizer, i.e. 55 kg per ha, were given to the tested soil. The area of each plot was 15 square meters, consisting of four rows of planting each 5 m in length; the distance between rows was 75 cm, and the distance between the tubers on the rows of plantings was 25 cm. To start germination after planting, all plots were irrigated. It should be noted that the rate of fertilization were carried out according to the procedure based on soil tests conducted at the station. During the growing season after planting, the weeds were eliminated manually for four times, and adding soil to the foot of shrubs was simultaneously done. When the plant height reached about 20 centimeters (45 days after planting), the other half of chemical fertilizer, i.e. 55 kilograms of per hectare was given to the land. Irrigation of plots was done similarly. In this study, 21 traits were studied.

Statistical calculations

To analyze the variance for measured traits, the mean of data obtained from each plot was used. The comparisons of irrigation periods were done based on LSD test. The comparison of varieties and the interaction of irrigation period × cultivars were performed according to Duncan test. Descending regression method was used to fit the most complete regression model between tuber yield (dependent variable) and other characteristics (independent variables). The SPSS, Minitab and Path analysis software were used for statistical analysis.

RESULTS AND DISCUSSION

ANOVA of the studied traits showed that there was significant difference among all of the studied traits but number of day until tuberization in terms of different irrigation levels and cultivars. Interaction of cultivars ×irrigation interval was observed only in terms of traits of plant height , number of main stem, diameter of main stem, number of tuber per plant , weight of tuber per plant and yield of the plant were studied. This showed that difference of cultivars was equal in different irrigation intervals. Effect of different irrigation levels on yield of tuber was significant in probability level of 1% (Table 1). Mean yield of tuber in cultivars was the highest during irrigation every 6 days and the lowest during irrigation every 18 days (Table 1).

Mean yields of tuber in potato cultivars were 24.24, 25.63 and 18.22 tons /hectare in stress free, medium stress and high stress conditions (Table 1). Considering the above results, it is observed that irrigation stress reduced crop by 8.61 tons/ hectare in medium stress condition compared with stress-free condition and 16.02 tons/hectare in high stress condition compared with stress-free condition and this figure considerably decreased. The obtained results in this research are in line with results of research by Babaei and Ghafari [11], Akbari and Motazavi [12] and Jefferies and Mackenson [17]. Serenade and Agria cultivars with tuber mean yields of 28.78 and 28.28 tons/hectare are among the productive cultivars and Draga cultivar with tuber mean yield of 24.41 tons/hectare is among the less productive cultivars (Table 1).

Table 1: Analysis of variance of the studied traits in different varieties of potato

S.O.V	DF	Mean of Squares						
		number of days to greening	percentage of green plants	Number of day to flowering	number of day to tuberization	plant cover percentage	Main stem number	plant height
Rep	2	0.13 ns	29.147 ns	0.667 ns	0.001ns	8.167 ns	0.014 *	0.503 ns
irrigation interval (a)	2	0.241 ns	64.582 ns	80.889 **	50ns	365.17 **	3.251 *	381.22 **
Error 1	4	0.352	30.546	0.889	0.001	2.833	0.002	1.085
Genotype (b)	5	15.441 ns	38.802 ns	187.28 **	68.4ns	749.51 **	7.458 **	174.68 **
a × b	10	0.063 ns	35.770 ns	1.933 ns	0.8ns	3.078*	0.053 **	4.6 **
Error 2	30	0.344	17.388	1.815	0.001	1.433	0.006	0.851
CV%		1.76	4.46	1.88	1.12	1.9	1.91	1.62

* and ** Significantly at $p < 0.05$ and < 0.01, respectively.

Continue Table 1-

S.O.V	DF	Mean of Squares						
		Percentage of 35-45 mm tubers	Percentage of 45-55 mm tubers	Percent of tubers larger than 55 mm	Percent of dry matter	Percent Secondary growth	Percentage Sprouted tubers in storage	storage loss percentage
Rep	2	23.344 ns	9.397 ns	11.423 ns	3.558 ns	0.028 ns	0.05 ns	6.675 ns
irrigation interval (a)	2	434.61**	524.95**	1625.88**	25.139*	0.203ns	0.411**	53.631 ns
Error 1	4	5.879	11.738	2.561	2.947	0.033	0.009	27.432
Genotype (b)	5	43.888**	52.288**	34.677**	63.683**	0.064ns	2.119**	25.879*
a × b	10	5.136 ns	15.913 ns	1.795 ns	2.103 ns	0.016ns	0.05 ns	9.290 ns
Error 2	30	12.02	8.169	3.76	1.323	0.031	0.035	9.478
CV%		14.28	12.6	13.08	4.95	28.91	13.175	27.49

* and ** Significantly at $p < 0.05$ and < 0.01, respectively.

As shown in Diagram 3, all the studied potato cultivars have higher tuber yield in stress-free condition than medium and high stress condition. With increasing stress, tuber yield is reduced more in Agria and Diamante cultivars by 10.52 and 14.17 tons/hectare so that agria and Diamante cultivars had reduced yield by 10.52 and 14.17 tons/hectare during irrigation every 12 days compared with the control treatment (every 6 days) and with increasing stress during irrigation every 18 days, this reduced yield reached 19.6 and 18.63 tons/hectare. While yield of Asterix cultivar was reduced to 9.14 tons/ hectare in the same condition. Therefore, considering the obtained results, it can be mentioned that Asterix cultivar shows lower sensitivity compared with other cultivars and where we face water shortage; we should not use Agria and Diamante cultivars because their yield is considerably reduced due to water shortage.

The tuber yield had a significant positive correlation with leaf area index, edible tubers percentage, plant cover percentage, plant height, main stem diameter, weight of tubers per plant, number of tubers per plant and the percentage of 45-55 mm tubers, while it had a significant negative correlation with the percentage of 28-35 mm tubers, the percentage of 35-45 mm tubers, storage loss percentage and the percentage of non-seeding tubers. The number of main stem showed a positive and significant correlation with the plant height and number of tubers per plant, and a significant negative correlation with the number of days until flowering. The number of tubers per plant had a significant positive correlation with the traits of vegetation percentage, plant height, number of main stem, weight of tubers per plant and tuber dry matter percentage (Table not included).

Descending regression analysis of tuber yield with all traits

Multiple regression analysis by descending regression was performed for tuber yield as the dependent variable for all the traits. In the analysis, the variables with significant impact that remained in the equation included: Percentage of green plants, tuber weight per plant, percentage of tubers between 35 and45 (Table 2).

The corrected explaining coefficient in the fitted model was equal to 0.98, which represented the 98% justification of existing changes in tuber yield by the variables mentioned. These three traits can be introduced as traits affecting the tuber yield. Although, determining the degree of correlation of traits with the yield is important, however, the simple correlation coefficient does not specify the nature of through relationship between the traits. In this regard, causality analysis was used to detect direct and indirect effects on tuber yield. The results of causality analysis are presented in Table 3 to infer the causal relationships between the dependent variable (tuber yield) and other remained traits in the regression model as independent variables. Based on this analysis, the tuber weight per plant had the most direct effect (0.812) on the tuber yield. Then, the average percentage of green plants had a positive correlation with the tuber yield (0.103). Also, the percentage of tubers between 35 and 45 had a direct and negative effect on the tuber yield.

Table 2: Analysis of variance of descending regression between the tuber yield and all studied traits

S.O.V	DF	SS	MS	F
Regression	3	18.99	6.33	141.87**
Residual	2	0.0892	0.0446	
R^2 adj: 0.98				
** Significantly at < 0.01, respectively				
Independent variables Percentage of green plants (X1) tuber weight per plant (X1) percentage of tubers between 35 and 45 (X3)				
Dependent variable:				
Y= -18.036-0.0969X1+0.0555X2+0.4424X3				

Table 3: Analysis of causality of tuber yield with all studied traits

traits	Direct effect	Indirect effect			Total correlation
		Percentage of green plants	tuber weight per plant	percentage of tubers between 35 and45	
Percentage of green plants	0.103	-	0.254	0.054	0.412
tuber weight per plant	0.812	0.032	-	0.131	0.976**
percentage of tubers between 35 and 45	-0.159	-0.036	-0.679	-	-0.872**
Residue: 0.159					

Descending regression analysis of tuber yield with the yield components

Multiple regression analysis by descending regression method was performed for tuber yield as the dependent variable with the yield components. In the analysis, the variables with significant impact that remained in the equation included: Plant height, number of main stem, dry matter percentage, and number of tubers per plant (Table 4). The corrected explaining coefficient in the fitted model was equal to 0.99, which represented the 99% justification of existing changes in tuber yield by the variables mentioned.

Table 4: Analysis of descending regression variance between tuber yield and the yield components

S.O.V	DF	SS	MS	F
Regression	4	19.072	4.7685	0.0305*
Residual	1	0.0079	0.0079	
R^2 adj: 0.99				
* Significantly at < 0.5, respectively				
Independent variables Plant height (X1) Main stem number (X1) dry matter percentage (X3) number of tubers per plant (X4)				
Dependent variable: yield of tuber				
Y= 10.32+0.296X1+0.6652X2+2.2640X3- 4.8414X4				

These four traits can be introduced as traits affecting the tuber yield. The results of causality analysis are presented in Table 5 to infer the causal relationships between the dependent variable (tuber yield) and other remained traits in the regression model as independent variables. Based on this analysis, the number of tubers per plant had the most direct effect (0.802) on the tuber yield. Then, the average plant height had a direct and positive correlation with the tuber yield (0.211). Also, the number of main stem and dry matter percentage had a direct and negative effect on the tuber yield.

Table 5: Descending regression analysis of tuber yield with phonologic traits

traits	Direct effect	Indirect effect				Total correlation
		Plant height	Main stem number	dry matter percentage	number of tubers per plant	
Plant height	0.211	-	-0.104	-0.059	0.61	0.66**
Main stem number	-0.176	0.125	-	-0.066	0.463	0.347
dry matter percentage	-0.627	0.019	-0.019	-	0.414	-0.211
number of tubers per plant	0.802	0.16	-0.102	-0.324	-	0.538**
Residue: 0.5						

A. Descending regression analysis of tuber yield with phonologic traits

Multiple regression analysis by descending method was performed for tuber yield as dependent variable with phenological traits. In the analysis, the variables with significant impact that remained in the equation included: Number of days to flowering, number of days to greening (Table 6). The corrected explaining coefficient in the fitted model was equal to 0.8, which represented the 8% justification of existing changes in tuber yield by the variables mentioned. These three traits can be introduced as traits affecting the tuber yield.

Table 6: Descending regression analysis of variance between the tuber yield and phenological traits (days to greening, days to growing tubers, days to flowering)

S.O.V	DF	SS	MS	F
Regression	2	16.8072	8.4036	11.0835*
Residual	3	2.2746	0.7582	
R^2 adj: 0.8				
* Significantly at < 0.5, respectively				
Independent variables Number of days to flowering(X1) number of days to greening (X2)				
Dependent variable: yield of tuber				
Y= 32.0306+0.2702X1-0.7608X2				

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