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Original Research Article

Modeling the potassium requirements of potato crop for yield and quality optimization

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Abstract

The intensity, quantity as well as capacity factors are important to predict the amount of nutrient in soil required for maximum plant growth. Sorption isotherm considers these three factors so believed to be one of the most important techniques in soil which control the fate and mobility of nutrients. The field experiment was conducted to find out site-specific and crop-specific potassium requirement for potato crop. The potassium adsorption isotherm was constructed and Freundlich model was used to theoretically work out different soil solution K levels (0, 5, 10, 15, 20, 25, and 30 mg L^{-1}). The K fertilizer doses were calculated against these specific soil solution levels. Field experiment was conducted with seven model based K fertilizer treatments (0, 49, 94, 139, 183, 228, and 273 kg K ha^{-1}) and three replications in Randomized Complete Block Design (RCBD) using potato as test crop. The results showed that growth parameters like plant height, leaf area and chlorophyll significantly contributed to potato tuber yield. Different yield response models were tested and it was observed that linear plus plateau and quadratic plus plateau predicted equally well the optimum fertilizer K rate both for yield and quality attributes of potato. For maximum potato tuber yield i.e.34.41 Mg ha^{-1} the economic optimum K was 100 kg ha^{-1}. Optimum fertilizer K rates (at 95 % relative yield) for potato tuber yield, dry matter percentage, protein, starch contents and vitamin C contents were 100, 103, 180, 230 and 200 kg K ha^{-1}, respectively. So, it is suggested that adsorption isotherm technique should be used to calculate site specific and crop specific fertilizer requirements of crops and 100 kg ha^{-1} is recommended as optimum potassium fertilizer for potato crop. Moreover, the K fertilizer application would improve crop quality that would support the quality based marketing system in Pakistan.

Keywords: Potato, Quadratic plus plateau, Adsorption isotherm, Yield, Quality

Introduction

Soil testing methods are essentially used as tool for monitoring soil fertility. However, they fail frequently, if used to predict optimal fertilizer requirements for crops. In Pakistan, the fertilizer recommendations are usually generalized and are given as a range (FAO, 2016) which are predicted from simple experiments in the fields and are extrapolated on all soils which is one of main reasons that crop responses to potassium fertilizers are very irregular and erratic (Mengel et al., 1998). Maximum profitability and environmental sustainability is only possible through fertilizer recommendations for maximizing the yield and quality (Thompson et al., 2017). These recommendations are developed through extensive field trials by studying the effect of different rates of fertilizers on crop yield and quality. To solve this problem, attempts should be made to predict fertilizer requirements using nutrient adsorption models. These models are based on different soil nutrient concentrations such as intensity, quantity and capacity factors. These all are important to predict the amount of soil nutrient requirements to adjust model based soil solution level required for maximum plant growth (Louison et al., 2015). The nutrient adsorption isotherms can be used for the estimation of fertilizers needed to adjust the soil solution nutrients to the level optimum for maximum yield (Kenyanya et al., 2014). The use of these models can only be possible through identification of critical solution level to get maximum plant growth which is specific for that particular soil and for that particular crop (Samadi, 2003, 2006). The adsorption characteristics are linked with type and quality of minerals in soil as well as other soil chemical properties, and vary greatly from soil to soil, in particular, the amount and type of clay minerals, cation exchange capacity and organic matter contents. So, the knowledge of the adsorption characteristics of soils can be an accurate and precise source of estimation for fertilizer requirement of potato crop.

In Pakistan, the use of potassium fertilizer for potato crop is not common (Hannan et al., 2011). The farmers either use generalized fertilizer for potato crop of even they do not use K fertilizer. So, the crop meets the potassium requirements from native soil K supply in tube well irrigated soils, and potassium from irrigation water in canal commanded areas. As potato is heavy K feeder and in most of the soils under potato crop the K is deficient so both sources cannot meet the K requirements of crop. The ratio of different nutrients in soil is affected by low or even no use of fertilizers for specific nutrients like P and K that restricts the crop growth and keeps it far below the genetic potential of the crop. Moreover, the potassium has pivotal role in the induction of resistance against different biotic and abiotic stresses including pests and disease resistance. The inadequate K supply to crop plants results in weakened plants which become more susceptible to various kinds of biotic and abiotic stresses such as disease stress, pests attack, heavy metal stress, frost, salinity, drought, nutritional stress, etc. These stresses affect the plant phenology and lower the ultimate yield and profitability.

Potato crop labeled as heavy feeder of K has high nutrient requirements and uptake of over 300 kg K ha^{-1} is common under optimum K supply (Perrenoud, 1993). As potassium deficiency has been reported by Directorate of Soil Fertility, Pakistan in most of the soils under potato crop in Pakistan so there exists a great opportunity to increase yield and quality of potato crop by improving nutrient management. Therefore, it appears rational that soil test results and fertilizer recommendations must be site-specific, model based (Wang et al., 2016) and calibrated scientifically. Scanty information is available on determination of optimum potassium fertilizer rates for vegetables in Pakistan so it is imperative to optimize the potassium fertilizer rate for maximizing potato yield by comparing and evaluating different yield response models in potato cropping sequence. In view of this background, field experiment was conducted to see the effect of potassium fertilizer rate using adsorption isotherm technique for potato crop by improving nutrient management to work out the site specific fertilizer recommendations for potato crop in Pakistan.

Material and Methods

A field study was conducted in potato growing tract of Pakistan (Farmer's field in Kassowal) to compare the effect of different potassium levels on the growth, yield and quality of potato by using sorption isotherm technique. The composite soil sample was collected and analyzed for the physical and chemical characteristics of the experimental field following the standard protocols (Ryan et al., 2001). The same was used to develop adsorption isotherm for the calculation of K fertilizer rates.

The potassium adsorption isotherm was constructed by using 2.50 g soil samples. These samples were equilibrated for 24 hours under shaking conditions at 25±1 °C with different K levels viz. 0, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 µg mL^{-1} in 25 mL $CaCl_2$ (0.01 M) solution. After achieving the steady state condition, the amount of K adsorbed was determined. Freundlich model was used to theoretically work out different soil solution K levels (0, 5, 10, 15, 20, 25, and 30 mg L^{-1}). The K fertilizer doses were calculated against these specific soil solution levels. Field experiment was conducted with seven model based K fertilizer treatments (0, 49, 94, 139, 183, 228, and 273 kg K ha^{-1}) and three replications in Randomized Complete Block Design (RCBD) using potato as test crop.

Field studies

The field experiment was conducted in Kassowal for the evaluation of different K fertilizer rates on the growth, yield and quality of potato tuber to optimize the fertilizer doze under field conditions. For this purpose, three replications were made and adsorption model based K fertilizer rates (0, 49, 94, 139, 183, 228, and 273 kg K ha^{-1}) were applied to potato crop as sulphate of potash using randomized complete design (RCBD). Potato seed tubers (cultivar Cardinal) were treated with fungicide Topsin-M and planted on ridges 75 cm apart at 20 cm spacing between plants. Plot size was 5m x 3m and there were four ridges per plot. All plots received basic application of 250 kg P_2O_5 (DAP) and 300 kg N ha^{-1}(Urea). Nitrogen was applied in three splits i.e. 1/3 at the time of sowing, second and third dose after 45 and 60 days of planting, respectively. An overall check (K=0) was also kept. The crop was irrigated with good quality irrigation water (canal water) with first irrigation after three days of planting. The subsequent irrigations were applied as and when required by the crop without any stress. The other plant protection measures and agronomic practices were carried out according to crop needs. Growth parameters like plant height, leaf area and chlorophyll contents were determined after 60 days of plant emergence. The crop was harvested at maturity on the development of potato tubers and data were recorded. Potato tubers were then graded manually into large (>75 g), medium (75-25 g) and small (< 25 g) sizes. Marketable tuber yield was determined and only marketable tuber data were reported in this manuscript. Internal and external K requirements of potato were worked out.

Physiological parameters

The physiological parameters of potato tubers were determined. Leaf area meter MK2 (Delta-T Devices Ltd, Cambridge, UK) was used for the measurement of leaf area. For the determination of chlorophyll contents, the chlorophyll meter (SPAD-502, Minolta Camera Co., Ltd, Japan) was used. The dry matter contents were determined by drying a known weight (W_1) of the sample in an oven at 105 °C to a constant weight (W_2), (AOAC, 1995).

Plant quality parameters

Total protein concentration was determined by following the method of Chapman and Parker (1961). For this purpose, one gram of well prepared (dried and ground sample) plant sample was digested in Kjeldahl flask by following the standard protocol. The digested material was distillated on micro Kjeldahl distillation apparatus and titrated against 0.1 N sulphuric acids. Data were used to calculate total protein concentration. The starch contents were determined by using the recommended method of Blankensh et al. (1993). Reducing sugars in the extract were estimated as described by Hortwitz (1960) while the vitamin C contents were estimated by following the method of Ruck (1961).

Statistical analysis

Data were subjected to statistical analyses using simple and multiple regression equations. Quadratic, square root, linear plus plateau, exponential and Quadratic plus plateau yield response models were tested using Graph pad ver.4.1. The treatment means were compared through analysis of variance techniques at 5% level of probability (Steel el al., 1997).

Results

Field studies were conducted to see the effect of potassium fertilizer rate using adsorption isotherm technique for potato crop. The basic analysis of the soil indicated that it was normal (EC_e = 0.75 dS m^{-1}), alkaline in reaction (pH_s = 7.81), low in organic matter (0.72 %), deficient in available nutrients (N = 0.04 %, P = 5.80 ppm and K = 71.00 ppm), calcareous in nature ($CaCO_3$ = 8.71 %) and loam in texture (Table 1).

Freundlich adsorption isotherm of the selected soil

Results showed that Freundlich isotherm of equilibrium K concentration against adsorbed K gave a highly significant linear relationship (Fig. 1). The potassium sorption data were fitted in the Freundlich equation that gave good results with highest value of coefficient of determination (0.96**). The potassium adsorption isotherm was constructed and Freundlich model was used to theoretically work out different soil solution K levels (0, 5, 10, 15, 20, 25, and 30 mg L^{-1}). The K fertilizer doses were calculated against these specific soil solution levels. For the adjustment of same soil solution K levels in the field experiment, the equivalent K fertilizer rates were calculated which varied from 0 to 237 kg ha^{-1} (Table 2). All potassium fertilizer rates were applied as basal dose of sulphate of potash during potato planting / at the time of sowing.

Effect of K fertilizer on growth, physiological and yield parameters

The results of the present study showed that plant height increased significantly with the application of K fertilizer (Table 3). It was improved from 40.67 cm with no K (T_0) to 56.33 cm with 139 kg K ha^{-1} (T_3) against soil solution level of 15 mg K L^{-1} which is 22.47 % increase as compared to control. Further increase in plant height with increasing K rate in T_4, T_5 and T_6 was statistically non-significant. The results of our study showed that potassium fertilization improved leaf area of potato crop up to 3438 cm^2 $plant^{-1}$ with K application @ 228 kg ha^{-1} (T_5) as indicated in Table 3 and it was 39.44 % higher when compared with control. Adequate supply of K improved chlorophyll contents of potato plant significantly. It increased from 35.00 % with native K to a maximum level of 43.67 % with K supply @ 273 kg ha^{-1} (T_6) equivalent soil solution level for this treatment was 30 mg K L^{-1} (Table 3).

Data (Table 4) showed that tuber yield was increased with increasing rate of potassium fertilizer and the maximum potato tuber yield (34.05 Mg ha^{-1}) was observed in the treatment T_3 where 139 kg K ha^{-1} was applied (Table 4). Further increase in K application rate (T_5 to T_7) could not bring about any significant change in potato tuber yield. The response of the crop to K application was due to low available status of K in soil before planting (Table 1).

The results showed that tuber dry matter contents increased with increase in potassium fertilizer rates up to a certain level and then decreased. The maximum dry matter contents (19.80 %) were observed in the treatment with K fertilizer rate of 183 kg ha^{-1} followed by18.14 % in the treatment with 273 kg K ha^{-1} (Table 4). In the present study, the increasing potassium levels increased the starch contents in tubers up to 81.20 % in the treatment T_5 with 228 kg ha^{-1} of potassium (Table 5). This increase was of 9.21 % when compared with control plots. A decrease in starch contents was observed with further increase in potassium rate.

Effect of K fertilizer on quality parameters

The results showed that protein contents of potato tubers increased with increase in potassium fertilizer rates (Table 5). This increase ranged from 11.67 % in T_0 to the maximum values of 13.28% in the treatment when K fertilizer was applied at 139 kg ha^{-1} i.e. 15 mg K L^{-1} of soil solution. In the present study, the reducing sugars concentration was maximum (42 mg per 100g fresh weight) in control treatment that decreased with increase in K application rate. The minimum concentration (26 mg per 100g fresh weight) was observed in the treatment where 273 kg K ha^{-1} was applied (Table 5).

The data showed that vitamin C contents in potato tubers increased with increasing level of K fertilizer and maximum (18.64 mg per 100g fresh weight) vitamin C contents were observed in the treatment with 228 kg K ha^{-1} (Table 5). This increase was statistically significant when compared with control treatment.

Evaluation of yield response models to predict economic optimum K rate for maximum tuber yield

The optimum potassium fertilizer rates for potato tuber yield predicted by the models tested i.e. square root, linear plus plateau, quadratic plus plateau, exponential and quadratic model were 67, 100, 100, 32 and 179 kg K ha^{-1}, respectively (Table 6). The five tested models showed minor difference in R^2 values however, they showed large variation in calculated optimum K fertilizer rates with similar R^2 values. This is illustrated by present study which exhibited variations in K rates between 32 and 179 kg K ha^{-1} (Table 6). The linear plus plateau models fitted the data with less bias on the basis of R^2 and S.E than the other models (Table 6).

Evaluation of yield response models to predict economic optimum K rate for quality parameters

The optimum potassium fertilizer rates for dry matter predicted by the models tested i.e. square root, linear plus plateau, quadratic plus plateau, exponential and quadratic model were 74, 103, 103, 428 and 144 kg K ha^{-1}, respectively (Table 7). In the present study, the optimum K fertilizer rate for potato dry matter predicted by quadratic model was lower than

exponential model. It has been observed that the optimum K fertilizer rate predicted by exponential model was very high i.e. 428 kg K ha^{-1} than the applied K rates.
The five tested models showed little difference in R^2 values however, they showed large variation in calculated optimum K fertilizer rates with similar R^2 values. The optimum K rate calculated by both quadratic plus plateau and linear plus plateau was (103 kg K ha^{-1}). Optimum K rate for protein predicted by square root, quadratic plus plateau, linear plus plateau, exponential and quadratic models were 74, 140, 180, 179 and 118 kg K ha^{-1}, respectively (Table 8). Optimum K rates for starch predicted by square root, quadratic plus plateau, linear plus plateau, exponential and quadratic models were 77, 222, 203, 561 and 150 kg K ha^{-1}, respectively (Table 9). Optimum K rates for vitamin C predicted by square root, quadratic plus plateau, linear plus plateau, exponential and quadratic models were 74, 103, 200, 430 and 84 kg K ha^{-1}, respectively (Table 10).
The optimum K rate for protein, starch and vitamin C calculated by the quadratic model was very less (0.283, 0.00142 and 0.00142 kg K ha^{-1} respectively) than the applied K rates. The standard error of the estimate also varied greatly among models. The linear plus plateau models fitted the data with less bias on the basis of R^2 and S.E than the other models.

External K requirements of potato crop

Optimum K requirement for maximum potato tuber yield was 100 kg K ha$^{-1.}$ (Table11). Regarding potato quality parameters K fertilizer was 180, 230 and 200 kg ha^{-1} for protein, starch and vitamin C content respectively.

Table 1: Physical and chemical properties of the soil used for experiment

Determinant	Unit	Value
EC_e	dS m^{-1}	0.75
pH_s	-	7.81
Organic matter	%	0.72
Total N	%	0.04
Available P	mg kg^{-1}	5.80
Available K	mg kg^{-1}	71.00
Cation exchange capacity	cmol^c kg^{-1}	9.26
$CaCO_3$	%	8.71
Sand	%	43.00
Silt	%	35.00
Clay	%	22.00
Textural Class	-	Loam (Typic Ustochrept)

Table 2: Freundlich model based K rate applied to potato crop in the field experiment

Treatment	**T_0**	**T_1**	**T_2**	**T_3**	**T_4**	**T_5**	**T_6**
Adjusted soil solution K levels (mg L^{-1})	0	5	10	15	20	25	30
K rate (kg ha^{-1})	0	49	94	139	183	228	273

Table 3:Effect of potassium on plant height, leaf area and chlorophyll contents of potato crop under field conditions (Average of three replicates)

Treatment	Adjusted soil solution K levels (mg L^{-1})	K rate (kg ha^{-1})	Plant height (cm)	Leaf area (cm^{-2} $plant^{-1}$)	Chlorophyll (%)
T_0	0	0	40.67c	2081d	35.00d
T_1	5	49	44.00c	2358c	36.00cd
T2	10	94	48.67b	2514c	39.33bc
T3	15	139	56.33a	2924b	39.00bc
T4	20	183	56.00a	3245a	41.00ab
T5	25	228	55.33a	3438a	42.67ab
T6	30	273	55.67a	3438a	43.67a

The means sharing same letters are not statistically different at 5% level of probability

Table 4: Effect of potassium on potato tuber yield, dry matter percentage and starch contents of potato crop under field conditions (Average of three replicates)

Treatment	Adjusted soil solution K levels (mg L^{-1})	K rate (kg ha^{-1})	Potato yield (T ha^{-1})	Dry matter (%)	Starch content (%)
T_0	0	0	20.04c	12.62f	73.56c
T_1	5	49	25.97b	16.23e	74.44c
T2	10	94	31.30a	17.75d	75.80bc
T3	15	139	34.05a	18.80b	75.76bc
T4	20	183	30.84ab	19.80a	78.20ab
T5	25	228	33.20a	18.39c	81.20a
T6	30	273	30.09ab	18.14c	79.56a

The means sharing same letters are not statistically different at 5% level of probability

Table 5: Effect of potassium on protein, reducing sugar, vitamin C contents of potato crop under field conditions (Average of three replicates)

Treatment	Adjusted soil solution K levels (mg L^{-1})	K rate (kg ha^{-1})	Protein (%)	Reducing sugar mg $(100g\ FW)^{-1}$	Vitamin C mg $(100g\ FW)^{-1}$
T_0	0	0	11.67c	42.00a	14.98c
T_1	5	49	11.80bc	40.33ab	15.40c
T2	10	94	12.11b	41.33ab	15.94bc
T3	15	139	13.28a	37.33ab	17.17bc
T4	20	183	13.16a	36.00bc	18.49ab
T5	25	228	13.27a	31.00cd	18.64a
T6	30	273	13.27a	26.00d	18.35a

The means sharing same letters are not statistically different at 5% level of probability

Table 6: Optimum rates of K fertilization predicted for potato yield by each model along with their coefficients of determination (R^2) and standard error of estimate values

Model	Optimum K rate (kg ha^{-1})	Coefficien t of determination (R_2)	Coefficients of equations		
			A	b	C
Square root	67	0.86**	2.16(19.46) *	0.5375(1.775)	0.03108(0.06043)
Quadratic plus plateau	100	0.98**	11.95(0.821)	0.091(0.0389)	0.00062(0.00037) Plateau value=32.70 (0.394)
Linear plus plateau	100	0.99**	10.83(0.776)	0.1639(0.01012)	Plateau value=32.71 (0.545)
Exponential / Mitscherlich	32	0.83**	-	25.49(9.468)	0.003737(0.00197)
Quadratic	179	0.92**	1.395(20.19)	0.02314(0.1470)	8.288(0.0004086)

*Values in parenthesis are standard error of estimate ** = (p = 0.05)

Table 7: Optimum rates of K fertilization predicted for dry matter by each model along with their coefficients of determination (R^2) and standard error of estimate values

Model	Optimum K rate (kg ha^{-1})	Coefficient of determination (R_2)	Coefficients of equations		
			A	b	c
Square root	74	0.92**	0.7592(12.42)	0.1871(0.844)	0.0585(0.02883)
Quadratic plus plateau	103	0.98**	0.7309(12.02)	0.03946(0.06944)	0.00041(0.000424) Plateau value=32.70 (0.394)
Linear plus plateau	103	0.99**	0.01112(0.054 86)	0.6805(12.92)	0.3696(18.78)
Exponential / Mitscherlich	428**	0.88**	-	23.40(81.44)	0.002725(0.01270)
Quadratic	144	0.92**	1.4113(12.83)	0.006962(0.07125)	2.44e-005(0.0001936)

*Values in parenthesis are standard error of estimate ** = (p = 0.05)
**optimum rate is very high than applied rates

Table 8: Optimum rates of K fertilization predicted for protein content by each model along with their coefficients of determination (R^2) and standard error of estimate values

Model	Optimum K rate (kg ha^{-1})	Coefficient of determination (R_2)	Coefficients of equations		
			A	b	c
Square root	74	0.82**	0.3849 (11.46)	0.09484 (0.04050)	0.05484 (0.004711)
Quadratic plus plateau	140	0.98**	0.05686 (11.67)	0.003070 (0.0004450)	3.159e-005(4.50e-005)
Linear plus plateau	180	0.99**	0.06247(0.01 14)	0.2401 (11.44)	Plateau value=13.23 (0.1639)
Exponential / Mitscherlich	179	0.80**	-	0.003352 (0.01008)	77.04 (196.8)
Quadratic	118	0.81**	0.2969 (11.45)	0.005027(0.01315)	1.76e-005(2026e-005)

*Values in parenthesis are standard error of estimate ** = (p= 0.05)

Table 9: Optimum rates of K fertilization predicted starch content by each model along with their coefficients of determination (R^2) and standard error of estimate values

Model	Optimum K rate (kg ha^{-1})	Coefficient of determination (R_2)	Coefficients of equations		
			A	b	c
Square root	77	0.90**	1.053 (73.59)	0.2595(0.08634)	0.015(0.03190)
Quadratic plus plateau	222	0.97**	0.6680 (73.68)	0.1707(0.1220)	8.942e-005(6.979e-005)
Linear plus plateau	230	0.99**	0.00437(0.03144)	0.6087(72.98)	0.8304(79.69)
Exponential / Mitscherlich	561**	0.83**	-	0.001444 (0.005986)	106.9 (38.14)
Quadratic	150	0.89**	0.9575 (73.30)	0.001612(0.0276)	5.69e-005(2.51e-006)

*Values in parenthesis are standard error of estimate ** = (P= 0.05)
**optimum rate is very high than applied rates

Table 10: Optimum rates of K fertilization predicted for vitamin C by each model along with their coefficients of determination (R^2) and standard error of estimate values

Model	Optimum K rate (kg ha^{-1})	Coefficient of determination (R_2)	Coefficients of equations		
			A	b	c
Square root	74	0.89**	0.5945(14.86)	0.1465(0.01918)	0.08469(0.01405)
Quadratic plus plateau	180	0.96**	0.1360(15.01)	0.004653(0.001454)	3.215e-005(18.46) Plateau value=32.70 (0.394)
Linear plus plateau	200	0.99**	0.002625 (0.01919)	0.2971(14.61)	0.2677(18.50)
Exponential / Mitscherlich	430**	0.65**	-	0.008223(0.002060)	183.6(58.24)
Quadratic	84	0.54**	0.4814(14.62)	0.00815(0.022631)	2.860e-005(2.749e-005)

*Values in parenthesis are standard error of estimate ** = (P= 0.05)
**optimum rate is very high than applied rates

Table 11: Economic optimum K rate predicted by Linear plus plateau model

Variable	Optimum K rate (kg ha^{-1})
Potato tuber yield (Mg ha^{-1})	100
Dry matter (%)	103
Protein (%)	180
Starch (%)	230
Vitamin C mg $(100g\ FW)^{-1}$	200

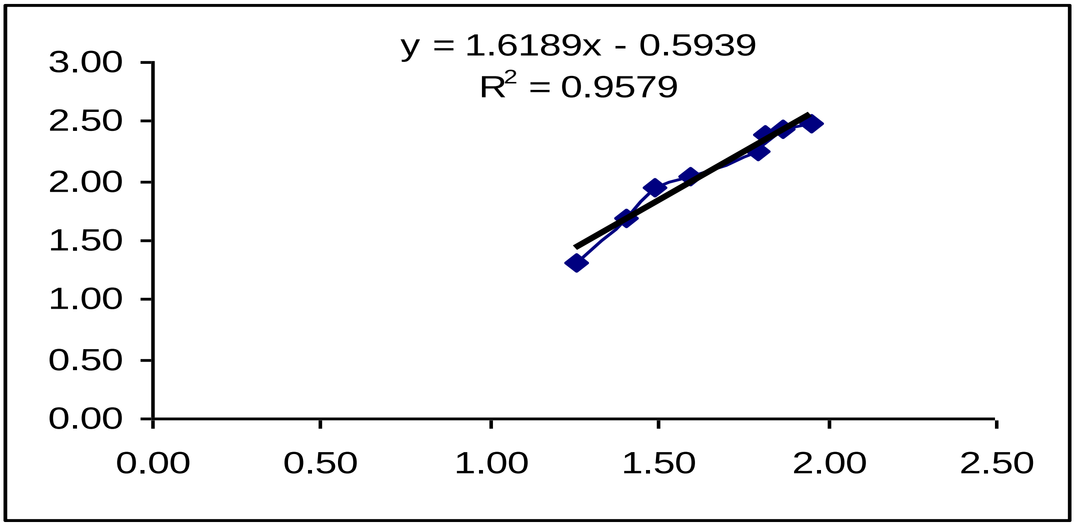

Figure 1. Freundlich adsorption isotherm for the selected soil

Discussion

Field studies were conducted to see the effect of model based potassium fertilizer rate using adsorption isotherm technique for potato crop. The fate of nutrients added in the soil depends upon the initial nutrient level in the soil while the soil solution concentration depends upon the rate of nutrient removal by the plants. It also depends desorption rate of nutrient from solid phase. The adsorption based K equilibrium solution level serves as an index of K availability. So, it has been reported that equilibrium K concentration using adsorption isotherm technique provides a better index of fertility of the soil (Singh and Jones, 1975). In the present study, Freundlich isotherm of equilibrium K concentration against adsorbed K gave a highly significant linear relationship (Fig. 1). It might be due assumption of unlimited sorption sites for heterogeneous medium in Freundlich model which in turn gave better correlation in soil with illite as the dominant clay mineral. The K fertilizer doses were calculated against these specific soil solution levels to see their effect on growth, yield and quality of potato crop. All potassium fertilizer rates were applied as basal dose during potato planting.

The results of the present study showed that plant height increased significantly with the application of K fertilizer. Although plant height is a genetic factor but it can be used as an indicator of crop performance and can be improved through balanced nutrition. Different growth, physiological and yield parameters contribute to the yield of the cop. For potato crop, the plant height, leaf area and chlorophyll contents are considered as important determinations used to describe crop performance (Taiz and Zeiger, 2006). These indices indicate the carbon assimilation rate of the potato plant system and its ultimate conversion in to sink (tubers).

The results of our study showed that potassium fertilization improved leaf area of potato crop. Leaf area is used an indicator for photosynthetic efficiency of the plants as it captures light thus an increase in leaf area results an improvement in photosynthetic rate. It has been observed that leaf area has critical role in studies of plant competition, plant nutrition, plant protection measures, plant soil-water relations and crop ecosystems (Mohsenin, 1986). Further increase in leaf area with increasing K rate was statistically non-significant. Similarly, Al-Moshileh et al. (2005) reported significant the improvement in growth parameters such as plant height, and leaf area of potato crop with increasing level of potassium fertilizer.

Chlorophyll is the real plant factory for manufacturing food. Adequate supply of K improved chlorophyll contents of potato plant significantly. The improvement in plant height, leaf area and chlorophyll contents (%) might be due to increase in photosynthetic rate which in turn related to improved stomatal conductance and higher ribulase bisphosphate carboxylase activity resulting in rapid rate of CO_2 fixation (Cakmak and Engels, 1999).

Results of our study showed that tuber yield was increased with increasing rate of potassium fertilizer. The response of the crop to K application might be due to low available status of K in soil before planting (Table 1). The farmers, in general depend on the native sources of K in irrigation water and soil minerals. The K requirement of potato crop is more that is required for carbohydrate metabolism and other physiological functions (Singh and Trehan, 1998; Incrocci et al., 2017) along with conversion of N and P in plants (Mengel and Kirkby, 1987). Potassium is known to facilitate the efficient translocation of photosynthates to the developing tubers (Beringer, 1978; Kavvadias et al., 2012). This fact is evident from the present study, that there was a progressive increase in tuber yield with each incremental level of added K up to 155 kg ha^{-1}. These results are in line with those of Hannan et al. (2011) who reported an increase in potato tuber yield with increasing K rate using isotherm technique. These might be due to translocation of more photosynthates to the tubers. In fact, potassium has critical role in the translocation photosynthates to storage organs (Romheld and Kirkby, 2010).

The results showed that tuber dry matter contents increased with increase in potassium fertilizer rates up to a certain level and then decreased. The decrease in dry matter contents with higher levels of potassium might be due to increase in water contents to maintain cell turgor pressure (Hannan et al., 2011). The results are in line with the previous studies conducted by Kumar et al. (2004) who have reported a decrease in dry matter contents with increasing K fertilizer rates. The potassium affects the water contents of the plasma thus increases the water contents of tubers. The reduction in dry matter contents with increase in potassium rate might also be due to translocation of more photosynthates and water to the tubers which in turn decreased the dry matter contents (Kavvadias et al., 2012).

Potassium stimulates the activity of different important enzymes in the plants such as starch synthatase that catalyzes simple sugars into complex polysaccharide i.e. starch (Mengel and Kirkby, 1987). In the present study, the increasing potassium levels increased the starch contents in tubers. A decrease in starch contents was observed in the present study that might be due to increase in water uptake through potassium application that restricted the number of amyloplasts in cytoplasm (Perrenoud, 1993). The same results have also been reported in previous work conducted by Hannan et al. (2011).

The results showed that protein contents of potato tubers increased with increase in potassium fertilizer rates in our study. These results are supported with the work of Khan et al. (2012 who reported that protein contents were improved with the application of potassium and these increased with increasing rates. This improvement in protein contents might be due to more conversion of photosynthates to protein and other storage components such as starch.

The concentration of reducing sugars in tubers is an important quality indicator for potato processing industries. In the present study, the reducing sugars concentration decreased with increase in K application rate. It appeared that still higher K levels need to be tested for finding out optimum K fertilizer rate for minimum reducing sugars in the potato tubers. Similarly, Hannan et al. (2011) reported a decrease in reducing sugars contents with increasing K fertilizer levels.

The data showed that vitamin C contents in potato tubers increased with increasing level of K fertilizer. This increase was statistically significant when compared with control treatment. It has been reported that potassium triggers the photosynthates production their translocation to tubers thus improves the conversion of photosynthates in to secondary metabolites such as vitamins (Mengel and Kirkby, 1987: Khan et al., 2012). Potassium has been reported to be engaged in the conversion of radiant energy into chemical energy. This metabolic energy is required for plant metabolism that results in increased production of proteins and starch, and decreases the reducing sugars contents thus improving the quality of potato tubers (Incrocci et al., 2017). The higher energy status resulting with optimum K supply promotes the synthesis of Vitamin C and other secondary metabolites.

In the present study, the optimum K fertilizer rate for tuber yield predicted by quadratic model was higher than exponential model while the optimum K fertilizer rate for potato dry matter predicted by quadratic model was lower than exponential model. These results are supported by the work of Hannan et al. (2011) where they reported the large variation in optimum K rate due to inappropriate model selection. They reported that Linear plus plateau was the most suitable model and best option for optimum K fertilizer recommendations as observed in these studies. The optimum K fertilizer rates predicted by different models varied greatly (Neeteson and Wadman, 1987; Incrocci et al., 2017)).

It has been observed that coefficient of determination is a poor criterion to select a model for optimization of K fertilizer rate. The same results have been reported in previous studies (Colwell, 1994; Hannan et al., 2011). The standard error of the estimate also varied greatly among models. So, it can be concluded from this study that the linear plus plateau model is best suited to describe the yield response of potato to K fertilizer and to predict the economic optimum K rates.

Conclusion

The results showed that growth parameters like plant height, leaf area and chlorophyll contents contribute significantly to potato tuber yield. The quality parameters like protein, starch and vitamin C contents were significantly affected by increasing K rates. Out of the tested models, linear plus plateau and Quadratic plus plateau predicted (equally well) the optimum fertilizer K rate for both for yield and quality attributes of potato crop. It was observed that the optimum fertilizer K rates (at 95 % relative yield) for potato tuber yield, protein, starch and vitamin C contents were 100, 180, 230 and 200 kg K ha^{-1}, respectively. So, it is suggested that adsorption isotherm technique should be used to calculate site specific and crop specific fertilizer requirements of crops. It can overcome the problem of sporadic responses to fertilizer as well. The K fertilizer application would increase the quality of crop that would support the quality based marketing system in Pakistan leading to improved profitability for the farmers.

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References

Al-Moshileh A, Errebhi MMA and Motawei MI, 2005. Effect of various potassium and nitrogen rates and splitting methods on potato under sandy soil and arid environmental conditions. Emir. J. Agric. Sci. 17:01-09.

AOAC, 2005. Official Methods of Analysis. 18th edn. Association of Official Analytical Chemists, Arlington, VA, USA.

Beringer H, 1978. Functions of potassium in plant metabolism with particular reference to yield, pp. 185-202. in Sekhon G.S (ed.), Potassium in soils and crops. Gurgaon, Haryana, India: Potash Research Institute of India.

Blankensh SM, Ellsuworth DD and Powell RL, 1993. A ripening index for banana fruit based on starch content. J. Hort. Technol. 3:338-339.

Cakmak I and Engels C, 1999. Role of mineral nutrition in photosynthesis and yield formation, pp. 141-168.in Rengel Z (ed.), Mineral nutrition of crops: mechanisms and implications. The Haworth Ptress, New York, USA.

Chapman HD and Parker F, 1961. Determination of NPK, pp. 150-179. In methods of analysis for soil, plant and water. Division of Agriculture, University of California, USA.

Colwell JD, 1994. Estimating fertilizer requirements: A quantitative approach. CAB International, Wallingford, UK.

FAO, 2016. Fertilizer use by crop in Pakistan. Natural Resources Management and Environment Department, Food and Agriculture Organization of the United Nations, USA. Available at: http://www.fao.org/docrep/007/y5460e/y5460e0.htm. Accessed on 22-08-2016.

Hannan A, Arif M, Ranjha AM, Abid A, Fan XH and Li YC, 2011. Response models to determine potassium fertilizer rates for potato crop on a calcareous soil in Pakistan. Comm. Soil Sci. Plant Anal. 42(6): 645-655.

Hortwitz W, 1960. Official methods of analysis. Association of Official Agric. Chemists, Washington, DC.9:314-320.

Incrocci L, Massa D and Pardossi A, 2017. New trends in the fertigation management of irrigated vegetable crops. Horticulturae 3, 37; doi:10.3390/horticulturae3020037.

Kavvadias V, Paschalidis C, Akrivos G and Petropoulos D, 2012. Nitrogen and potassium fertilization responses of potato (*Solanum tuberosum*) cv. Spunta. Comm. Soil Sci. Plant Anal. 43(1-2): 176-189.

Kenyanya O, Mbuvi HM, Muthengia JM and Omayo EK, 2014. Use of adsorption isotherm models to determine potassium fertilizer acreage doses for optimum maize growth and yields in Nyamira County, Kenya. Intl. J. Agri. Crop Sci. 8 (15): 1525-1536.

Khan MZ, Akhtar ME, Mahmood-ul-Hassan M, Mahmood MM and Safdar MN, 2012. Potato tuber yield and quality as affected by rates and sources of potassium fertilizer. J. Plant Nutr. 35(5): 664-677.

Kumar D, Singh BP and Kumar P, 2004. An overview of the factors affecting sugar content of potatoes. Ann. Appl. Biol. 145: 247-256.

Louison L, Omrane A, Ozier-Lafontaine H and Picart D, 2015. Modeling plant nutrient uptake: Mathematical analysis and optimal control. Lect. Notes Pure Appl. 4: 193–203.

Mengel K and Kirkby EA, 1987. Principles of plant nutrition, 4th Ed. International Potash Institute, Worblaufen-Bern, Switzerland.

Mengel K, Rahmatullah and Dou H, 1998. Release of potassium from the silt and sand fraction of loss-derived soils. Soil Sci. 163: 805-813.

Mohsenin N, 1986. Physical properties of plant and animal materials, Gordon and Breach Science Publishers, New York, USA.

Neeteson JJ and Wadman WP, 1987. Assessment of economically optimum application rates of fertilizer N on the basis of response curves. Fert. Res. 12: 37-52.

Perrenoud S, 1993. Fertilizing for higher yield potato, IPI Bull. 8, 2nd Ed. International Potash Institute, Worblaufen-Bern, Switzerland.

Romheld V and Kirkby EA, 2010. Research on potassium in agriculture: Needs and prospects. Plant Soil 335: 155-180.

Ruck JA, 1961. Chemical methods for analysis of fruits and vegetable products. Res. St. Summer Land. Res. Branch Canada. Deptt. of Agric. 1154.

Ryan J, Estefan G and Rashid A, 2001. Soil and plant analysis laboratory manual, 2nd edition, International Center for Agriculture in Dry Areas (ICARDA), Syria, 172p.

Samadi A, 2003. Predicting phosphate requirement using sorption isotherms in selected calcareous soils of western Azarbaijan province, Iran. Comm. Soil Sci. Plant Anal. 34(19-20): 2885-2899.

Samadi A, 2006. Potassium exchange isotherms as a plant availability index in selected calcareous soils of Western Azarbaijan Province, Iran.Turk. J. Agric. 30: 213-222.

Singh BB and Jones JP, 1975. Use of sorption-isotherms for evaluating potassium requirement of plants. Soil Sci. Soc. Am. J. 39:881-886.

Singh JP and Trehan SP, 1998. Balanced fertilization to increase the yield of potato. in Barar MS and Bansal SK (eds.), Proceedings of the IPI-PRII-PAU Workshop on Balanced Fertilization in Punjab Agriculture, International Potash Institute, Worblaufen-Bern, Switzerland.

Steel RGD, Torrie JH and Dicky DA, 1997. Principles and procedures of statistics a biometrical approach. (3rd Ed.). pp. 204-227. McGraw Hill Book International Co., Singapore.

Taiz L and Zeiger E, 2006. Plant defenses: Surface protectants and secondary metabolites, pp. 283-308. In Taiz L and Zeiger E (ed.), Plant Physiology, Sinauer Associates, Sunderland, MA.

Thompson RB, Incrocci L, Voogt W Pardossi A and Magán JJ, 2017. Sustainable irrigation and nitrogen management of fertigated vegetable crops. Acta Hortic. 1150: 363–378.

Wang C, Boithias L, Ning Z, Han Y, Sauvage S, Sánchez-Pérez JM, Kuramochi K and Hatano R, 2016. Comparison of Langmuir and Freundlich adsorption equations within the SWAT-K model for assessing potassium environmental losses at basin. Agric. Water Manage. doi.org/10.1016/j.agwat.2016.08.001.