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Effect of P fertilization on yield and quality of oat (*Avena sativa* L.) fodder on two different textured calcareous soils

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Abstract

Oat is an important fodder for animals in Pakistan. Phosphorus is a quality nutrient for fodders. The use of P for oat is negligible. Thus a field study was conducted to evaluate the effect of P fertilizer on yield and quality of oat fodder on sandy clay loam and loamy sand calcareous soils. Sorption isotherms were constructed by equilibrating 2.5 g soil with 25 mL of 0.01 M $CaCl_2$ solution containing 0, 20, 40, 60, 80, 100, 200, 300, 400 and 500 µg P mL^{-1} as KH_2PO_4 and shaking for 24 hour. Against theoretical soil solution P levels of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, and 0.50 mg P L^{-1}, fertilizer doses for oat (fodder) were computed by using empirically derived Freundlich equation. It was noted that P adsorption increased but percent marginal adsorption of P decreased by increasing its level of application in both the soils. P adsorption was more in sandy clay loam soil (88.30%) than loamy sand soil (80.42%) at the lowest P application rate of 20 mg kg^{-1}. At the highest rate of P application (500 mg P L^{-1}) percent adsorption of P was 44.38% in sandy clay loam soil and 29.12% in loamy sand. Different P fertilizer doses were required for different soils to develop the same level of solution P. Maximum oat fodder yield and dry matter contents obtained were 41.48 t ha^{-1}, 20.21% at 0.30 mg P L^{-1} from sandy clay loam soil and 17.87 t ha^{-1}, 16.65% at 0.25 mg P L^{-1} from Loamy sand soil. P concentration, crude protein, crude fiber and ash (%) contents in oat fodder increased significantly with increasing P application rates.

Keywords: P fertilization, adsorption isotherm, oat fodder quality

Introduction

Mineral fertilizers played a great role towards improving crop yields but main constraint in achieving proven crop potential is imbalanced use of fertilizers, particularly low use of P as compared to N. The optimum rates of P application play a vital role in improving yields of most crops (Cisar *et al*., 1992). A better P supply increases mineral P concentration in plants (Halliday and Trenkel, 1992). Soils of Pakistan are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0%) in nature. When P fertilizer is added, part of it goes to soil solution and is taken up by plants or precipitates, while rest goes to exchange sites and is adsorbed (Wandruszka, 2006). Olsen method is widely used as a test for available P in alkaline, calcareous soils. P sorption isotherm technique has been suggested by many investigators (Fox and Kamprath, 1970; Holford, 1997) to determine the amount of P, required to bring its concentration in soil solution to the level optimum for maximum plant growth. This technique is not widely used as some scientists consider it time consuming and cumbersome (Memon *et al*., 1991) while others consider it more accurate than conventional soil P test (Klages *et al*., 1988). This technique is based on the assumption that a certain soil solution P concentration is required to supply adequate P to plants. Values of 0.2 and 0.3 mg L^{-1} in soil solution are considered adequate for most plants to attain near maximum growth (Beckwith, 1965; Borrero *et al*., 1988; Pena and Torrent, 1990; Chaudhry *et al*., 2003).

Soil solution P levels can be determined by different equations which show P adsorption relationships (Huang, 1998; Zamuner and Culot, 1999). The Langmuir and the Freundlich equations described the adsorption phenomena satisfactorily (Boschetti *et al*., 1998). Ghanbari *et al*. (1998) fitted the Langmuir and the Freundlich isotherms to P adsorption data for 10 calcareous soils and observed that adsorption data closely followed the Freundlich isotherm and linear relationship was observed between P adsorption and desorption. The slope of line was different for different soils. Gregory *et al*. (2005) stated that the Freundlich isotherm is a heterogeneous binding model and is widely applicable in measuring the heterogeneity of soils. Freundlich equation describes well the P adsorption over a limited range of P concentration (Barrow, 1978; Bhal and Toor, 2002; Delgado *et al*., 2002; Mahmut, 2003; Hussain *et al*., 2006).

In Pakistan farmers are using only nitrogen fertilizers for fodder crops while the use of P fertilizer is negligible. These crops are often grown on marginal lands. Hence the production is low and quality is poor. Quality of fodder crops in Pakistan is too poor to meet the animal's nutritional requirement (Khan *et al*., 2003). Fodders are the most valuable and cheapest source of food for livestock having rich source of metabolizable energy, nutrient elements, carbohydrates and protein. With quality nutritional fodder, milk production can be increased up to 100% (Maurice *et al*., 1985).

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The importance of P in the diet of animals is that its highest requirements are during lactation, early growth and for reproduction. High producing cows need much more P than cows producing at average or low levels. Dry cows or cows that are not producing milk need less P than lactating cows due to high content of P in milk. A cow producing 100 pounds of milk daily would require 100g of P and would secrete 43g of P in milk; a continous supply of P is needed in the animal diet to increase milk production. If there is the deficiency of P in animal diet a lot of diseases like Pica, milk fever, lactation inefficiency in milch animals and Austiomalysia, etc will occur (Anonymous, 1988). Bolland and Brennan (2005) reported that P concentration (%) in shoot of oat to attain 90% yield is 0.23%. Phosphorus deficiencies occur in animals when forages containing 0.10-0.12 % P are fed (Black *et al*., 1949; Pinchak *et al*., 1989). The animals require fodders containing 0.35-0.40% P and if the weight of the animal is 100, 200, 300 and 400 kg, they correspondingly need 8.1, 13.2, 14.0 and 14.4 g P daily (Iqbal *et al*., 2004).

Oat (*Avena sativa* L) is an important Rabi fodder under irrigated conditions either grown as sole crop or sown together with berseem. Oat provide nutritious fodder in the dry month of May and are relished by animals particularly horses and mules. When mixed with berseem, oat provides balanced feed to milch animals (Younis and Azam, 2003). Moreover, improved fertilizer management of oats may help to enhance crop quality and thus the potential for producing high quality oats (Mohr *et al*., 2004). Hussain *et al*. (1993) reported that oats produced more fodder and less crude protein with advancing crop maturity. The crop should be harvested at booting stage that provides an optimum compromise between forage yield and quality. Maximum green fodder, dry matter yields and crude protein contents were recorded when oats were harvested at 50 percent flowering. Keeping in view the above discussion, present study was conducted to assess the effect of P fertilization on the yield and quality of oat fodder.

Materials and Methods

Two sites with Sandy clay loam and Loamy sand soils were selected at Postgraduate Agriculture Research Station, University of Agriculture Faisalabad and Research and Development Rakh Khairewala District Layyah, respectively. Composite soil samples were collected from 0-30 cm depths and analyzed for Physical and chemical characteristics (Table 1) by using the methods as described by Bigham (1996). Lime and particle size analyses were determined by the method of Moodie *et al*. (1959) and available P was measured by the procedure as given by Watanabe and Olsen (1965).

P adsorption isotherms and application of Freundlich equation to compute P doses

Phosphorus adsorption capacities of the soils were determined by shaking 2.5 g soil with 25 mL 0.01M $CaCl_2$ containing P concentrations of 0, 20, 40, 60, 80, 100, 200, 300, 400 and 500 µg P mL^{-1} prepared from KH_2PO_4 for 24 hours at 20^oC. The soil solutions were filtered through Whatman No. 41 filter paper and P concentration was measured using ascorbic acid method (Murphy and Riley, 1962) and sorption isotherms were constructed according to the methods described by Rowell (1994). The amount of P adsorbed was calculated from the difference of P added and P remained in solution after P equilibrium was established. The adsorption data were fitted to the empirically derived Freundlich equation (Pant and Reddy, 2001) as under to compute P fertilizer doses.

$$X/m=K_f\,(EPC)^{1/n}$$

Linear form of the equation=Log X/m=Log K_f+ 1/n (Log EPC)
X/m=Amount of P adsorbed per unit of soil (µg g^{-1})
EPC=Equilibrium P concentration in soil solution (µg mL^{-1})
K_f is proportionality constant for Freundlich equation (mg P kg^{-1})
1/n is empirical constant expressed in L kg^{-1}.

The plots between Log (x/m) vs. Log (EPC) were drawn. The parameters K_f and 1/n were estimated by regression of the logarithmic form of the data obtained from adsorption isotherms. P doses were computed (Table-2) by putting the adsorption data into the linear form of the above equation to attain soil solution P levels of 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, and 0.50 mg L^{-1}.

Table 1. Physico-chemical properties of soils.

Property	Loamy sand	Sandy clay loam
ECe (dS m^{-1})	1.14	1.05
pHs	8.1	7.7
$CaCO_3$ (%)	6	7
Organic matter (%)	0.4	0.6
Available P (mg kg^{-1})	4.7	6.6
Available K (mg kg^{-1})	57	120
Sand (%)	83	58
Silt (%)	6	20
Clay (%)	11	22
Textural Class	Loamy sand	Sandy clay loam

Field experiment

Field experiments were conducted on two soils i.e. loamy sand and sandy clay loam. There were ten treatments and six replications laid out in Randomized Complete Block Design (RCBD). Whole P (calculated) as Diammonium Phosphate (DAP) and recommended K (65 kg ha^{-1}) was applied as Potassium Sulphate at the time of sowing. Nitrogen @ 100 kg ha^{-1} was applied as Urea in two splits i.e. half at sowing and half with first irrigation. The crop was harvested at booting stage and green fodder yield data were recorded. The dry matter contents were determined by taking difference between fresh and oven dry weight of the plant samples (expressed on percentage bases). Plant samples were analyzed for, P concentration, crude protein, crude fiber and ash (%) contents. Data thus generated were statistically analyzed according to Steel and Torrie (1980). The comparisons among the treatment means were made by using Duncan's Multiple Range Test at 5 % probability level (Duncan, 1955).

Table 2. P fertilizer doses computed by Freundlich equations.

Soil solution P levels	Loamy sand		Sandy clay loam	
	P	P_2O_5	P	P_2O_5
mg L^{-1}	--------kg ha^{-1}-------			
0.00	0	0	0	0
0.05	10	22	17	40
0.10	16	36	29	66
0.15	21	48	38	88
0.20	26	59	47	108
0.25	30	69	55	127
0.30	34	79	63	145
0.35	38	88	71	162
0.40	42	96	78	178
0.50	49	113	91	210

Results and Discussion

Laboratory study

P adsorption by soils

The amount of P adsorbed (x/m) increased with progressive increase in amount of added P but the increase was not linear (Figure 1). The marginal adsorbed P, expressed as percent of the applied P, decreased in both the soils. The percent P adsorption (Table 3) indicated that at highest level of added P (500 mg P L^{-1}) the adsorption was (44.38%) by sandy clay loam soil. It was followed by loamy sand soil, which at the same amount of applied P, adsorbed 29.12 %. While at the lowest level of P application i.e. 20 mg L^{-1} sandy clay loam and loamy sand soils adsorbed 88.30 and 80.42% P, respectively. Thus the highest amount of P was adsorbed by sandy clay loam due to high clay and $CaCO_3$ contents. The lowest amount was adsorbed by loamy sand soil having less $CaCO_3$ and clay. Wandruszka (2006) reported that P adsorption in calcareous soils was significant only at relatively high P concentration due to $CaCO_3$. Morais *et al*. (1996), Samadi (2003) and Zhou and Li (2001) also reported similar results. Kumar and Singh (1998) observed that amount of adsorbed P increased with the increase in initial level of P in the solution in all the five calcareous soils under investigation. The proportion of added P, which was adsorbed expressed in percentage followed a reverse trend, decreasing progressively from lowest level of 5 mg kg^{-1} (92% in Beni soil and 96% in Jamaur soil) to the highest level of 100 mg kg^{-1} (76% in Kathgodam soil and 88 % in Jamaur soil).

Table 3. P adsorption by soils.

P added (ppm)	Loamy sand	Sandy clay loam
	P adsorbed %	
0.00	0.00	0.00
20.00	80.42	88.30
40.00	74.35	88.60
60.00	69.48	88.30
85.87	64.10	84.90
114.67	60.57	82.28
200.00	49.32	70.08
302.00	42.52	62.25
400.00	35.68	53.17
500.00	29.12	44.38

Freundlich adsorption isotherms

The adsorption isotherms were examined according to the linear form of the Freundlich equation [Log x/m vs. Log EPC] Figure 2. The values of exponent (1/n) were found less than one in both the Freundlich equations (Table 4). The values of 1/n observed in this study ranged from 0.7020 to 0.7219 L kg^{-1}. In this study the value of exponent (1/n) was less than one which indicates equilibrium P concentration in soil. If 1/n value is more than one it indicates low equilibrium P concentration in soil. In this study P concentration in soil solution increased with increasing level of added P. Similarly values of exponent (1/n) were observed less than one by a number of researchers. According to Zhou and Li (2001), 1/n values ranged from 0.327 to 0.663 L kg^{-1} and Hussain *et al*. (2006), 1/n values ranged from 0.575 to 0.975 L kg^{-1}. K_f is an indicator of P adsorption capacity of soils. In these studies the value of K_f for sandy clay loam soil was 75.45 µg g^{-1} and for loamy sand soil was 40.03 µg g^{-1}. High K_f value 75.45 µg g^{-1} of soil indicated high P adsorption capacities, while low value indicated low P adsorption capacities at low P concentration. Zhou and Li (2001) stated that low K_f values indicated low P adsorption capacities at low P concentrations (≤1 mg P L^{-1}). Moreover, a large amount of P may be retained by the process of precipitation at high P concentration, therefore, K_f only indicated the amount of P adsorbed at low P concentration and not the precipitation.

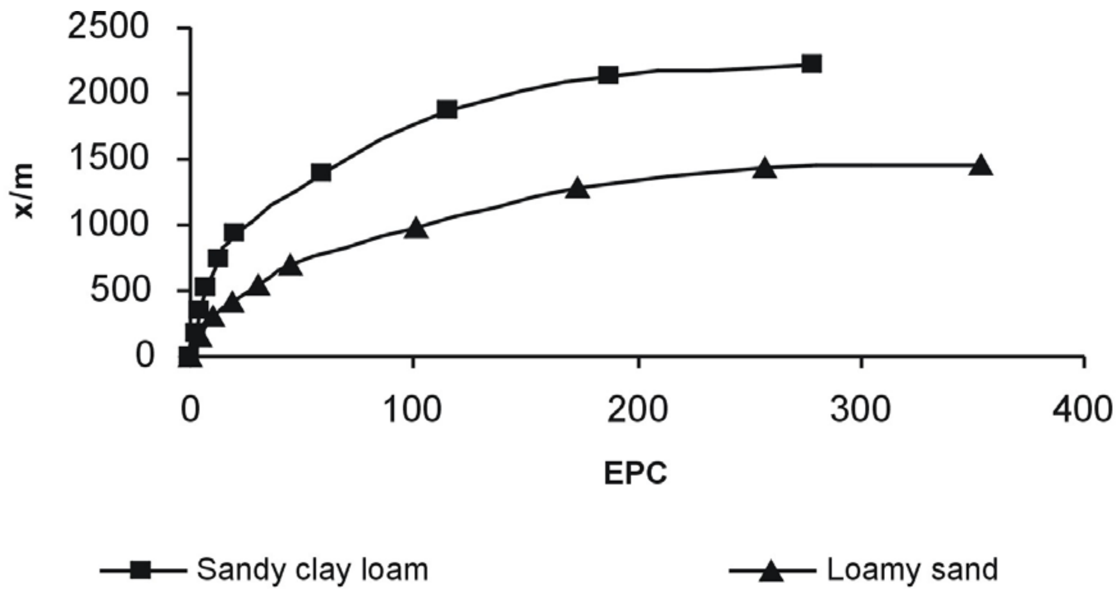

Figure 1: P adsorption by soils

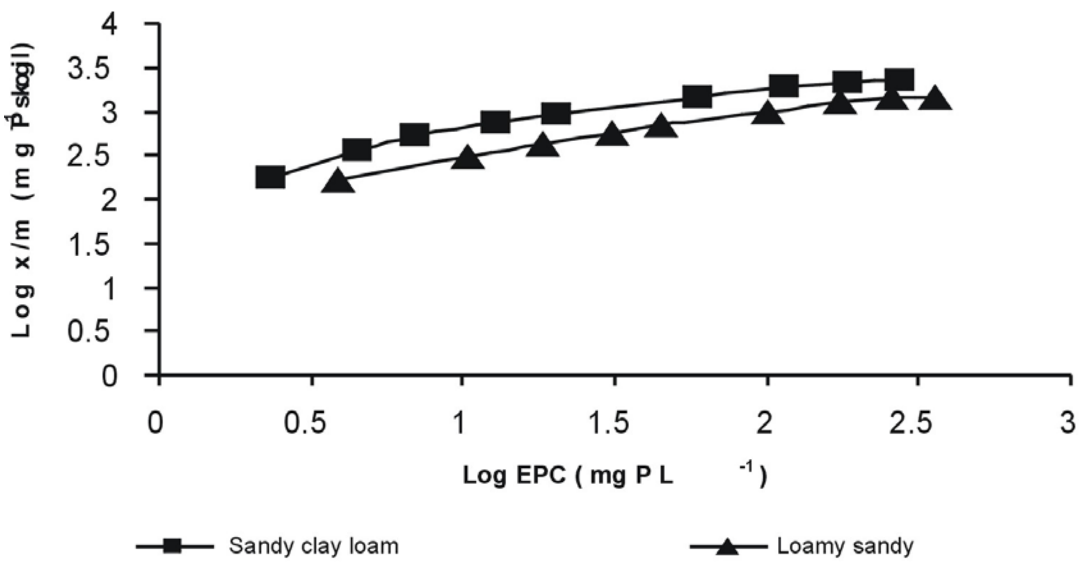

Figure 2: Freundlich adsorption curves

Table 4. Empirically derived Freundlich equations.

Soil	**Model Form** $P = a\,C^{b/a}$ / Derived form $x/m = K_f\,(EPC)^{1/n}$	Linear form
Loamy sand	$x/m = 40.03\ (EPC)^{0.7020}$	Y=0.7020 (Log EPC) +1.6024
Sandy clay loam	$x/m = 75.45\ (EPC)^{0.7219}$	Y=0.7219 (Log EPC) +1.8777

Field study

Green fodder yield (t ha^{-1}) of oat as affected by P fertilizer

Green fodder yield data of oat crop presented in Table 5 revealed that maximum green fodder yield of 41.48 t ha^{-1} was obtained where P was applied @ 63 kg ha^{-1} to sandy clay loam soil (against soil solution P level of 0.30 mg L^{-1}). Similarly, maximum green fodder yield of 17.87 t ha^{-1} was obtained where P was applied @ 30 kg ha^{-1} to loamy sand soil (against soil solution P level of 0.25 mg L^{-1}). There was no increase in green fodder yields above these rates of P application i.e. 63 and 30 kg ha^{-1} to sandy clay loam and loamy sand soils, respectively. At high P application rates, the yield was static and no further increase in yield was observed. The oat fodder yield obtained from sand clay loam soil was higher than loamy sand soil. Similarly, P fertilizer requirement was more on fine (sandy clay loam) soil than on coarse (Loamy sand) soil. In Pakistan, P recommendations given are crop specific but not site specific. From the present results, it is evident that recommendations should be site specific and crop specific. Oat green fodder yield responded differently to different P levels but response to higher P levels (> 0.35 mg L^{-1}) was not observed. This was due to imbalanced plant nutrients. Excess P causes Zn deficiency which reduced the fodder yield. Similar, results were reported by Yadav *et al.* (2000), Munir *et al*. (2004) and Younis and Azam (2003).

P Concentration in Plants

The data regarding the effect of P fertilizer on P concentration in oat fodder are presented in Tables 5. The P concentration (%) in oat fodder increased significantly with increasing P application rates and with more P in soil solution with the highest rates. Maximum P concentration (0.21%) in oat plant was observed where P was applied @ 91 and 49 kg ha^{-1} (soil solution P level of 0.50 mg L^{-1}) to sandy clay loam and loamy sand soils, respectively. The P concentration (%) in plant increased significantly with increasing level of P application and more available P in soil solution. Normally plant roots having wider contact with soil are better extractor of P from soil and feed well to above ground plant. This is due to extensive root system (Tisdale *et al*., 1997; Kumaresan *et al.,* 2002; Munir *et al.*, 2004. Bolland and Brennan (2005) reported that P concentration (%) in oat shoot to attain 90% yield was 0.23%.The P concentration of forage crops is important since low P content in the animal diet leads to “aphosphorosis” which is a serious disease in livestock. Due to P deficiency, the fertility of livestock may seriously be affected (FAO, 1984). In animals deficiency of P occurs when forages containing 0.10-0.12% P are fed (Black *et al.*, 1949; Pinchak *et al*., 1989). Thus, the quality of oat fodder was improved with respect to P concentration.

Dry matter (DM) contents %

The data regarding the effect of P fertilizer on DM contents (Table 5) revealed that maximum DM contents of oat were 20.21% with the application of 63 kg P ha^{-1} in sandy clay loam soil (against soil solution P level of 0.30 mg L^{-1}). Similarly, maximum DM contents of oat were 16.65% where P was applied @ 30 kg ha^{-1} in loamy sand soil (against soil solution P level of 0.25 mg L^{-1}). There was no increase in dry matter contents above P application rates of 63 and 30 kg ha^{-1} to sandy clay loam and loamy sand soils, respectively. At higher levels of P application, the DM contents did not increase significantly. The soils under study were P deficient, so P application improved the soil P status from deficient to optimum (Table I) which caused improvement in DM contents. The increase in DM contents confirmed the necessity of P application in P deficient soils for obtaining better yields (Ahmad *et al*., 1999). Memon (1996) has reported that soil containing available P < 10 mg kg^{-1} is considered to be deficient. Similar finding has been reported by Rashid (1994) that more than 90 % soils of Pakistan require high to moderate P fertilization for optimum plant growth.

Quality of oat fodder

Quality fodder is needed for better performance of animals. The parameters used to describe forage quality are crude protein, crude fiber, ash contents (Soest, 1985). Addition of P fertilizer is necessary as it improves both quality and quantity of the green fodder (Dhillon *et al*., 1998). Phosphorus application to soil regulates Mg uptake which prevents tetany (a disease) in animals (Lock *et al*., 2000).

Crude Protein (CP) %

The effects of P on crude protein contents in oat fodder are presented in Table 6. The crude protein contents increased with P fertilizer use for oat crop. The maximum crude protein contents (11.04%) were in oat fodder supplied with 91 kg P ha^{-1} to sandy clay loam soil i.e. soil solution P of 0.50 mg L^{-1}. Maximum CP contents (7.96%) were in oat fodder supplied with 49 kg P ha^{-1} in loamy sand soil (against soil solution P level of 0.50 mg L^{-1}). This indicated better utilization of N with increasing P inputs. Crude protein contents in oat fodder increased significantly with increasing P application rates over control. The increase in crude protein contents was due to the facts that P is an important structural component of DNA and RNA. The Phosphate group in nucleic acids bridges the RNA or DNA, respectively. DNA is the carrier of genetic information and RNAs function in protein synthesis (Mengel and Kurkby, 2001). Similarly, Chaudhary *et al*. (1984); Hussain, (1991) also reported that crude protein contents were increased with P application.

Table 5. Effect of P on green fodder yield and P concentration in plant and dry matter contents of oat fodder.

Soil solution P levels mg P L^{-1}	Loamy sand			Sandy clay loam		
	Green fodder yield	P concentration	Dry matter	Green fodder yield	P concentration	Dry matter
	t ha^{-1}	------------%----------		t ha^{-1}	------------%------------	
0.00	6.87f*	0.101g	11.46d	14.42f	0.102g	9.89e
0.05	9.83e	0.119f	12.53d	21.29e	0.124f	12.47d
0.10	12.00cde	0.139e	12.87cd	25.76dc	0.135e	14.18c
0.15	14.87bcd	0.157e	13.28bc	28.45d	0.154d	15.27c
0.20	16.77ab	0.166d	14.47ab	32.29c	0.167d	17.38bc
0.25	17.87a	0.174d	16.65a	34.15bc	0.174c	18.47ab
0.30	16.58ab	0.187c	16.25a	41.48a	0.198b	20.21a
0.35	14.48abc	0.191c	15.89a	40.23a	0.201ab	19.98a
0.40	13.48cde	0.202b	15.04b	39.86ab	0.208a	18.19ab
0.50	12.75de	0.216a	14.16bc	39.13ab	0.211a	17.18bc

*Means sharing the same letters are statistically significant at 5% level of Probability

Table 6. Effect of P fertilization on the quality of oat fodder.

Soil solution P levels mg P L^{-1}	Loamy sand soil			Sandy clay loam soil		
	Crude protein	Crude fiber	Ash	Crude protein	Crude fiber	Ash
	------------------------------%------------------------------					
0.00	5.16g*	37.13g	11.07i	6.82h	31.29i	10.35h
0.05	5.73f	37.54g	11.67h	7.28g	32.17h	10.57gh
0.10	6.47e	38.33f	13.40g	7.52fg	32.59g	10.83fg
0.15	6.66e	39.55e	13.85f	7.81f	33.19f	11.08ef
0.20	6.74de	39.05ef	14.61e	8.99e	33.66e	11.31e
0.25	7.03cd	40.45d	15.01de	9.63d	34.09d	12.42d
0.30	7.30bc	41.98c	15.27cd	10.04c	34.18d	12.82c
0.35	7.39b	43.15b	15.47c	10.40b	35.12c	13.17b
0.40	7.49b	43.84b	15.93b	10.58b	35.77b	13.42b
0.50	7.96a	46.97a	16.51a	11.04a	36.40a	14.58a

*Means sharing the same letters are statistically significant at 5% level of Probability

Crude fiber (CF) and ash %

The effects of P on crude fiber and ash contents in oat fodder are presented in table 6. The results revealed that crude fiber and ash contents increased significantly with increasing P application rates. The maximum crude fiber and ash contents were 36.40 and 14.58% in oat fodder where P was applied @ 91 kg ha^{-1} (against soil solution P level of 0.50 mg L^{-1}) to sandy clay loam soil. Similarly, maximum crude fiber and ash contents were 46.97 and 16.51% in oat fodder where P was applied @ 49 kg ha^{-1} (against soil solution P level of 0.50 mg L^{-1}) to loamy sand soil. This increase in crude fiber contents was due to the dry matter accumulation with P application (Chand *et al*., 1992). Similarly, Ayub *et al*. (2002) reported that crude fiber contents were increased with P application along with N. Increase in ash % is due to increase in mineral matter (Soest, 1985).

Conclusion

P fertilizers application is necessary for oat fodder crop along with recommended NK fertilizers. It improves fodder yield and quality, hence the palatability and digestibility of fodder crops is increased which resultantly increases milk yield of milch animals, gain in live weight of ewes and control of diseases.

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