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Full Length Research Paper

Effect of nitrogen and phosphorous rates on fertilizer use efficiency in lettuce and spinach

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In this study, Lettuce (*Lactuca Sativa*) and Spinach (*Spinacea Oleracea*) were used as a case study vegetable crop to compare models for estimating Fertilizer Use Efficiency based on nitrogen and phosphorous fertilizer and nitrate concentration. Field studies were conducted to measure yield, nitrate, Fertilizer Use Efficiency, response to applied Nitrogen and phosphorous fertilizer in two plants. The area was located between 25° 21´ E longitude and 51°38´ N latitude in the North of Varamin city, (Tehran province, Iran) in the alluvial plain of Varamin. Soils family were fine, mixed, active, thermic, typic haplocambids based on Soil Taxonomic system (1999). Plants were received five rates of Nitrogen (0.0, 150, 200, 250 and 300 kg Nha^{-1}) as a urea in split applications and five rates of Phosphorous (0.0, 37.5, 50, 62.5 and 75 kg P_2O_5 ha^{-1}) as a triple super phosphate (TSP). Data for plant fresh mass (tonha^{-1}) and Nitrate uptake (nitrate) (mgkg^{-1}) were recorded. Models were described the data for cultivar quite well, with correlation coefficients of 0.80 and above. All of models for Lettuce and Spinach production were compared graphically and analytically. The model coefficients were then used to make improved estimates of fertilizer recommendations for field production of Lettuce and Spinach in Iran. Results showed that most suitable mode for prediction of fertilizer use efficiency was Y=16.77+0.0522N+0.0576P (R^2=0.81) in lettuce (N: kg and P: kg P_2O_5ha^{-1} in lettuce. Based on we could predicted fertilizer use efficiency that help to agricultural practice management until nitrogen and phosphorous fertilizers used suitable and avoid leaching of nitrogen in lettuce culture.

Key words: Fertilizer use efficiency, Lettuce, Spinach.

INTRODUCTION

Urea hydrolyzes rapidly following its application to soils. Ammonium accumulates in the application zone and pH increases due to the consumption of H^+. The resultant pH from urea hydrolysis in most soils ranges from 7.0 to 9.0 (Kissel et al. 1998). As soil pH rises, the proportion of NH_3 over NH_4 increases and volatilization can occur when urea is surface applied (Ferguson et al., 1984). Investigations have found that >50% of surface applied urea-N could be lost through NH3 volatilization (Al-Kanani et al., 1991, Abdel-Maged,1997). Gasser (1964) reported that volatilization take place directly after addition of ammonium sulfate. Similar conclusion was reported by Shammas et al. (1997). To solve Volatilization problems and enhance urea efficiency, it is essential to slow down urea hydrolysis to avoid both build up and pH increase in soil. Maintaining a low pH in the vicinity of the urea granule reduces urea hydrolysis and volatilization. Addition of H3PO4 reduced volatilization by retarding hydrolysis and by reducing the pH increase from urea hydrolysis (Bremner and Douglas, 1971). Ammonia volatilization could also be decreased by mixing urea with triple super phosphate (TSP) applied to an acid soil (Fan and Mackenzia, 1993), or mixing with KCl (Ouyang et al., 1998). Filed and laboratory experiments done by authors during 1997/1998 showed that 50% reduction in ammonia volatilization upon mixing urea fertilizer with elemental sulfur (Shahin and Suliman, 1998). The objectives of the present work were studying efficiency of N uptake by plants in soil and studying the effect of triple super phosphate (TSP) blended Urea fertilizer on plant properties.

MATERIALS AND METHODS

A field experiment was set up in 2007 at the research station of the Varamin agricultural research center, Iran.

Table 1. Soil characteristics in area

Texture	Clay Loam
Available Cu ($mgkg^{-1}$)	1.5
Available Zn ($mgkg^{-1}$)	1.06
Available Mn ($mgkg^{-1}$)	9.36
Available Fe ($mgkg^{-1}$)	3.44
Available K ($mgkg^{-1}$)	419
Available P ($mgkg^{-1}$)	6.82
Organic Carbon (%)	0.71
Carbonates (%)	15.9
pH	7.54
Electrical Conductivity (dSm^{-1})	2.95
Saturation Percent (%)	40
Depth (cm)	0-30

Table 2. Mean of squares yield, fertilizer use efficiency and nitrate in lettuce.

Sources	Degree of Free	Nitrate	Fertilizer Use Efficiency	Yield
Replication	2	^{ns} 792753	^{ns} 313.723	61.374 ^{ns}
Nitrogen	4	6591098**	16585.121**	610.59**
Error	8	226331	108.794	42.782
Phosphorous	4	^{ns} 34983	** 168.023	44.204**
Nitrogen and Phosphorous	16	^{ns} 24960	* 85.603	16.187*
Error	40	14885	35.812	8.238
C.V	-	17.66	10.52	9.98

ns, * and ** is non significantly and significantly at probable level 5% and 1%, respectively.

Preparation of lettuce seedling

Lettuce seeds (variety Romaine) were planted on 9th March, 2007. Plots were 15 m long and 5 m wide and consisted of five rows on 40 cm spacing and row spacing was assigned 20 cm for a total of 93 plants per plot (62, 000 plant) in Lettuce. Lettuce heads were harvested on 4th June, 2007. Irrigation was used at 8000 m^3ha^{-1}. The seedlings were planted on both sides of each line. Spinach sown on 9th September, 2007. Plots were 15 m long and 5 m wide and consisted of three rows on 40 cm spacing and row spacing was assigned 5 cm for a total of 450 plants per plot (300000 plant per ha). Spinaches were harvested on 3rd November 2007 and Irrigation water was used at 3200 m^3ha^{-1}. The seedlings were planted on both sides of each line.

Experimental design

The Spilt Plot experiment design (5*5) in complete randomized blocks was used. The trail contains 25 experimental plots 3×5 m for each. The sources of nitrogen and phosphorus were used urea and triple super phosphate. That nitrogen fertilizer were added at rate of 0, 150, 200, 250 and 300 kg Nha^{-1} and the phosphorous fertilizer were added at rate of 0, 37.5, 50, 67.5 and 75 kg $P_2O_5ha^{-1}$ and applied broadcast prior to planting. All treatments were replicated three times with irrigation and pest control following recommended cultural practices (Hochmuth and Maynard, 1996).

Sampling

Plant Samples: After 12 and 7 weeks of planting, four complete leaves were collected from each replicate for analysis in lettuce and Spinach, respectively. At the end the experiment, fresh yield was determined.

Soil sample: Surface soil samples (0-30 cm) representing each experimental treatment were collected before planting, then transported to the laboratory, air dried, then sieved using 2 mm sieve and stored for analysis.

Laboratory analyses: After determination of fresh weight, the leaves were cut down to thin section, then dried at 70ºC for 48 h, then weight and milled. Dry matter was used for chemical analysis.
A total of 75 lettuce (*Lactuca sativa*) and 75 Spinach samples grown in Varamin, Iran were analyzed for their nitrate contents using Kejehldal method (Bremner and Mulvaney, 1982). A composite soil sample (top 30 cm) was collected and analyzed for EC (Electrical conductivity of soil extract was measured usning EC meter), pH (Soil pH was measured potentiometrically using pH meter), organic carbon (Walkley and Black, 1934), available phosphorous (Olsen and Sommers, 1982), available K (Flame photometer), available Mn, Fe, Cu and Zn (Spectrophotometer), Carbonates (Nelson, R.E. 1982), soil texture by hydrometer (Klute, 1986). Table 1 showed Soil characteristics in area based on laboratory analysis.

Table 3. Mean of squares yield, fertilizer use efficiency, and nitrate concentration in leaf and stem in spinach.

Nitrate	Fertilizer use efficiency	Yield	Degree of free	Variant resource
ns 1512361	ns 683.008	ns 97.433	2	Replication
** 4838742	5811.145**	935.573**	4	Nitrogen Treatment
62843	294.715	290.997	8	Error
ns 223102	* 83.467	* 20.268	4	Phosphorous Treatment
* 234175	ns 28.177	ns 4.131	16	Nitrogen and Phosphorous
99081	29.549	6.386	40	Error
15.97	15.79	14.71	-	C.V

ns, * and ** is non significantly and significantly at probable level 5% and 1%, respectively.

Table 4. Effect of nitrogen factor on yield, fertilizer use efficiency and nitrate in Lettuce.

Nitrate ($mgkg^{-1}$ FW)	Fertilizer Use Efficiency (%)	Yield ($tonha^{-1}$)	Nitrogen Treatment ($kgNha^{-1}$)
69.87D	-	19.97B	0
244.3CD	81.36A	24.41B	150
532.3BC	77.20AB	30.88A	200
858.7B	70.08B	35.04A	250
1749A	55.88C	33.53A	300
400.6	8/783	5.508	LSD

Means followed by different letters are significantly differ for each other according to Duncan multiple range test at *P* = 0.05.
Statistical probably is at 5% level (P>0.01).

Table 5. Effect of phosphorous factor on yield and nitrate in lettuce.

Nitrate ($mgkg^{-1}$ FW)	Yield (ton/ha)	Phosphorous treatment ($kgP_2O_5ha^{-1}$)
52.15C	26.43C	0
55.98BC	28.03C	37.5
56.20ABC	28.46BC	50
60.55A	30.29AB	62.5
59.65AB	30.61A	75
4.416	2.118	LSD

Means followed by different letters are significantly differ for each other according to Duncan multiple range test at *P* = 0.05.
Statistical probably is at 5% level (P>0.01).

Statistical analysis: The obtained data were performed according to the general linear model procedure using Mstatic, Excel and SAS software.

RESULTS AND DISCUSSION

Fresh weight of leaves: TableS 2 and 3 showed mean of squares yield, fertilizer use efficiency, and nitrate in Lettuce and Spinach, respectively. Significant effects could be detected on most of the studied growth characters (yield, nitrate, fertilizer use efficiency) when compared Lettuce and Spinach. Nitrogen, phosphorous and interaction of them had significant effect on yield, fertilizer use efficiency but only nitrogen had significant effect on nitrate in Lettuce. This result was obtained in research years ago (Sqrensen et al., 1994; Vogtmann et al., 1984). Nitrogen, phosphorous had significant effect on yield, fertilizer use efficiency but nitrogen and interaction of nitrogen and phosphorous had significant effect on nitrate in Spinach.

Yield: The results of Tables 4, 5, 6 and 7 showed marked increased in fresh weight of leaves of the treatments received Urea and Triple super phosphate compared those untreated. The increments in fresh weight varied between 24-33 ton/ha in effect of factor nitrogen in lettuce. Where those of fresh weight factor varied between 28-30 ton/ha in effect of phosphorous factor in lettuce. Treatment

Table 6. Effect of nitrogen factor on yield, fertilizer use efficiency and nitrate in spinach.

Nitrate (mgkg^{-1} FW)	Fertilizer use efficiency (%)	Yield (ton/ha)	Nitrogen treatment(kgNha^{-1})
1216D	0B	7.597C	0
1749C	40.55A	12.17BC	150
1977B	39.11A	15.64B	200
2142B	49.87A	24.94A	250
2772A	42.58A	25.55A	300
211.1	14.46	4.612	LSD

Means followed by different letters are significantly differ for each other according to Duncan multiple range test at $P = 0.05$.
Statistical probably is at 5% level (P>0.05).

Table 7. Effect of phosphorous factor on yield and nitrate in spinach.

Nitrate (mgkg^{-1} FW)	Yield (tonha^{-1})	phosphorous treatment (kgP_2O_5ha^{-1})
31.31B	15.72B	0
33.86B	16.68B	37.5
34.46AB	17.35AB	50
34.55AB	17.23B	62.5
37.92A	18.91A	75
4.012	1.573	LSD

Means followed by different letters are significantly differ for each other according to Duncan multiple range test at $P = 0.05$.
Statistical probably is at 5% level (P>0.05).

fertilizer use efficiency varied between 55-81 as the source of nitrogen and 55-60% as the source of nitrogenin lettuce. Where 40-42 and 33-37% as the source of nitrogen and phosphorous varied in spinach, respectively.

Data presented in Table 6 showed that the yield of fresh spinach was increased with increasing N level. The highest yield was recorded for 300 kg N/ha, while the lowest yield was obtained by 150 kg N/ha. The yield of spinach, it also increased with increasing the phosphorus rate and reach its maximum value (18.91 ton/ha) by applying 75 kg P_2O_5/ha (Table 7).

Statistical analysis showed that, while the effect of Nitrogen and Phosphorous fertilizer was significant, addition of nitrogen had led to highly significant variation with phosphorous. Phosphorous fertilizer had no significant effects on the nitrate content nitrogen fertilizer had significant effects on the nitrate content of the Lettuce and spinach. The results indicated significant differences (P=0.05) on the nitrate concentrations among lettuce and Spinach. Based on Tables 4 and 5, fertilizer was 200 kg N/ha and 62.5 kg P_2O_5/ha for lettuce. Based on Tables 6 and 7, Maximum yield (37 ton/ha) was obtained at 250 kg N/ha and 50 kg P_2O_5/ha, similar results was reported by Yong Bo et al. (2003), Everett (1980). Analysis of variance proved significant difference in yield for nitrogen and phosphorous treatment in lettuce and spinach. In general, yield in spinach was relatively low comparing with that of lettuce.

Fertilizer use efficiency: Fertilizer use efficiency by lettuce varied between 81-55 and 55-59%, 39-42 in effect of nitrogen and phosphorous factor while it was 33-37% in spinach. The statistical analysis of complete randomized blocks design (CRBD) using general linear model showed significant differences for fertilizer use efficiency of lettuce and spinach treated with urea and triple super phosphate compare with those received no fertilizer. Fertilizer use efficiency of lettuce significantly was up to 50 kg P_2O_5/ha using phosphorous in lettuce (Table 5) but it was decreased in using nitrogen (Table 4). That other researches reported by Brown and Smith 1966, Barker and Maynard 1967, Zebarth et al. 2004 and WenQi et al. 2004. It could occurred for maximum fertilizer use efficiency as was obtained at 200 kg N/ha and 50 kg P_2O_5/ha in lettuce (Tables 4 and 5). Based on Tables 6 and 7, maximum fertilizer use efficiency was 150 kg N/ha and 50 kg $P_2O_5$$^{-1}$ha in spinach. Analysis of variance proved significant difference in fertilizer use efficiency for nitrogen and phosphorous treatment in lettuce and spinach.

In general, fertilizer use efficiency in spinach was relatively low comparing with that of lettuce.

Nitrate accumulation: Yield and Nitrate uptake tend increased gradually with N application rate. The highest levels of N (300 kg Nha^{-1}) resulted in the maximum N uptake, plant yield in lettuce (1749 mgkg^{-1}) and spinach

Table 8. Correlation coefficient of nitrogen effect between studies characteristics in lettuce and spinach.

Plant	Parameter	Yield	Fertilizer use efficiency	Nitrate
Lettuce	Yield ($kgha^{-1}$)	1		
	Fertilizer use efficiency (%)	0.58ns	1	
	Nitrate ($mgkg^{-1}$ FW)	0.86ns	0.25ns	1
Spinach	Yield (kgha-1)	1		
	Fertilizer use efficiency (%)	0.77^{ns}	1	
	Nitrate ($mgkg^{-1}$ FW)	$^{*}0.91$	0.76^{ns}	1

Table 9. Correlation coefficient of phosphorous effect between studies characteristics in Lettuce and Spinach.

Plant	Parameter	Yield	Fertilizer use efficiency	Nitrate
Lettuce	Yield ($kgha^{-1}$)	1		
	Fertilizer Use Efficiency (%)	**0.98	1	
	Nitrate ($mgkg^{-1}$ FW)	0.58ns	0.65ns	1
Spinach	Yield ($kgha^{-1}$)	1		
	Fertilizer Use Efficiency (%)	$^{**}0.99$	1	
	Nitrate ($mgkg^{-1}$ FW)	0.51^{ns}	0.53^{ns}	1

(2772 $mgkg^{-1}$) (Tables 4 and 6).

Maximum nitrate was obtained at 300 kg/Nha in lettuce (1749 mg/kg) (Table 4) and in spinach (2772 mg/kg) (Table 6). It was shown that overall mean nitrate content was 1216-2772 and 69.9-1749 mg/kg. The results also show nitrogen in Spinach and Lettuce grown in Varamin, respectively. Nitrate content was European standard, it was more than European standard fertiliztion with 300 kg N/ha. (The Commission of the European Communities, 1997). Nitrate concentration in the leaves of the treatments received no nitrogen varied from 69-1216 mg/kg as the source of nitrogen in lettuce and spinach, respectively (Tables 4 and 6), meanwhile, nitrate concentrations in the where those nitrate varied between 52-31 mg/kg as the source of nitrogen in lettuce and spinach, respectively (Tables 5 and 7). On the present of nitrogen, nitrate level increased from 244-2772 mg/kg in lettuce and spinach (Tables 4 ans 6), where on the present of phosphorous, varied from 33-60 mg/kg in lettuce and spinach (Tables 5 and 7). Analysis of variance proved significant difference in nitrate concentration for nitrogen treatment in lettuce and spinach. These results were confirmed by Al Redhaiman et al. (2003). In general, concentration of nitrate in lettuce was relatively low comparing with that of spinach. Statistical analysis showed that nitrate content as the result of using nitrogen factor was significant higher than those of other treatments. It showed importance of nitrogen in increaseing nitrate in plants that was referred by Al Redhaiman et al. 2003. Nitrate content was lower than the EU (1993) recommended level for spinach except 300 kg N/ha treatment and was lower than the EU (1993) recommended level for lettuce.

Correlation coefficient: Tables 8 and 9 showed correlation coefficient of nitrogen and phosphorous effect among studies characteristics in lettuce and spinach. Fertilizer use efficiency had not significant correlation with yield and nitrate in lettuce and spinach (Table 8) Where had significant positive correlation with yield in lettuce and spinach (Table 9). Therefore increasing usage phosphorous fertilizer increased fertilizer use efficiency in lettuce and spinach.

Figures 1 and 2 showed relation between phosphorous fertilizer with fertilizer use efficiency and yield in lettuce and spinach, respectively. It had significant positive correction in using phosphorous fertilizer in lettuce and spinach. Correction was more of higher phosphorous fertilizer in spinach than lettuce. Thus based on Figures, similar trend was recorded by Choudhary et al. (2003), Pathak et al. (2004) and Zebarth et al. (2004). Based on this results, the relation between fertilizer use efficiency and nitrogen and phosphorous was non linear and positive and it was similar among lettuce and spinach. The most suitable treatment was 250 kg N/ha for optimum fertilizer use efficiency in lettuce and spinach. Tables 10, 11 and 12 showed regression equations for response nitrogen fertilizer rates through N: nitrogen fertilizer rate (kg Nha^{-1}) and p: phosphorus fertilizer rate (kg $P_2O_5ha^{-1}$).

Regression equations: It was obtained a regression equation for response interaction of Nitrogen (N: kg Nha^{-1}) and Phosphorous (P: kg $P_2O_5ha^{-1}$) fertilizer rates

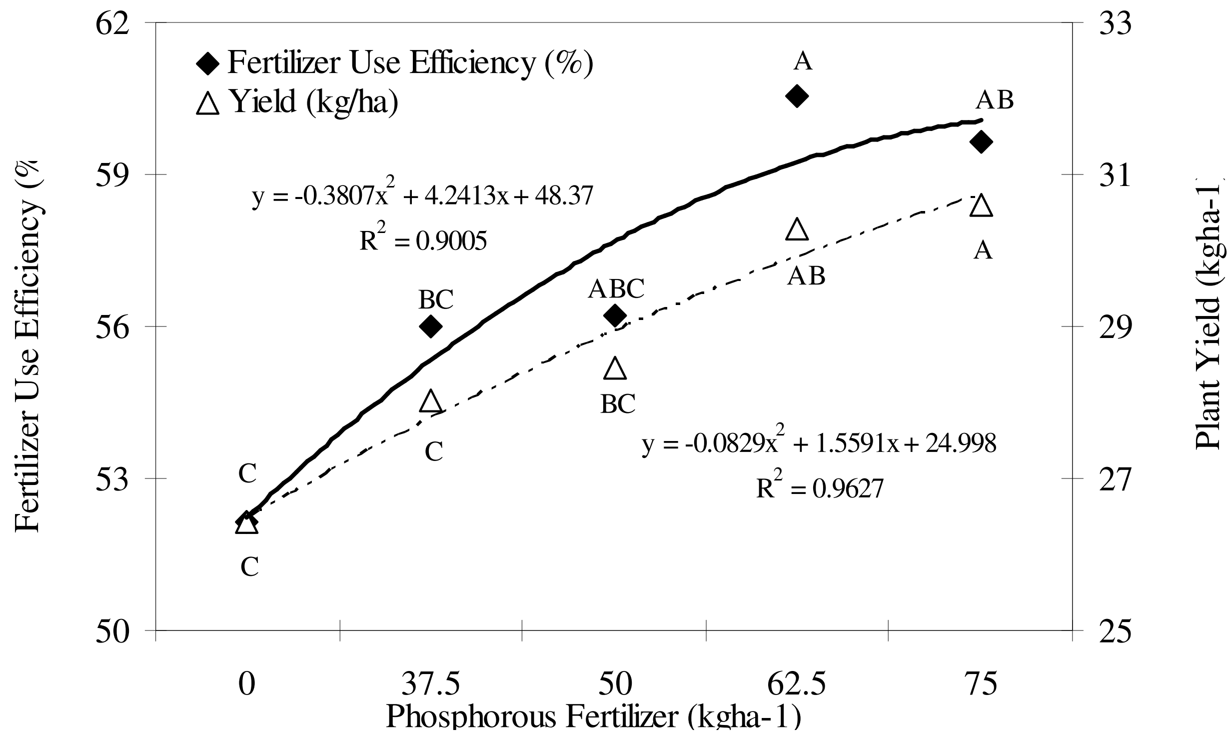

Figure 1. Relation between phosphorous fertilizer with fertilizer use efficiency and yield in lecttuce.

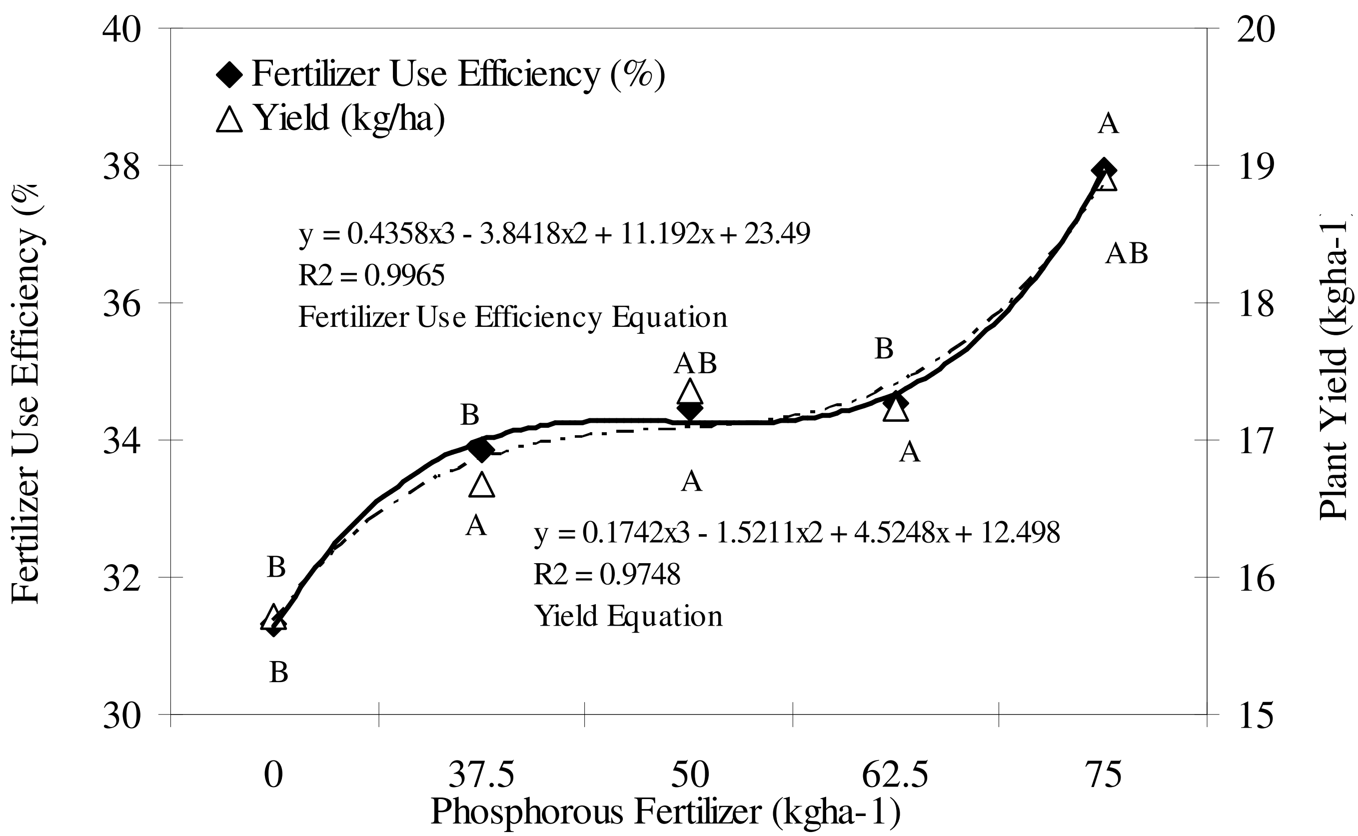

Figure 2. Relation between phosphorous fertilizer with fertilizer use efficiency and yield in spinach.

Table 10. Regression equations for response Nitrogen fertilizer rates through N: nitrogen fertilizer rate (kg Nha^{-1}).

Plant	Response variable (Y)	Regression equation	R^2
Lettuce	Yield (ton/ha)	$Y = -1.012N^2 + 9.87N + 10.34$	0.96
	Nitrate (mg/kg)	$Y = 105.0N^2 - 232.7N + 234.1$	0.98
	Fertilizer use efficiency (%)	$Y = -2.43N^2 + 8.65N + 73.7$	0.99
Spinach	Yield (ton/ha)	$Y = -0.63N^3 + 5.5N^2 - 9.2N + 12.2$	0.97
	Nitrate (mg/kg)	$Y = 64.2N^3 - 568.1N^2 + 1808.7N - 92.8$	0.99
	Fertilizer use efficiency (%)	$Y = -5.96N^2 + 45.22N - 35.66$	0.89

Table 11. Regression equations for response Phosphorous fertilizer rates through P: phosphorous fertilizer rate (kg $P_2O_5ha^{-1}$).

Plant	Response variable (Y)	Regression equation	R^2
Lettuce	Yield (ton/ha)	$Y = -0.08P^2 + 1.56P + 24.99$	0.96
	Fertilizer use efficiency (%)	$Y = -0.38P^2 + 4.24P + 48.37$	0.90
Spinach	Yield (ton/ha)	$Y = 0.17P^3 - 1.52P^2 + 4.52P + 12.49$	0.97
	Fertilizer use efficiency (%)	$Y = 0.43P^3 - 3.84P^2 + 11.92P + 23.49$	0.99

Table 12. Regression equations for response interaction of Nitrogen and Phosphorous fertilizer rates through N: nitrogen fertilizer rate (kg Nha^{-1}) and P: phosphorous fertilizer rate (kg $P_2O_5ha^{-1}$).

Plant	Response variable (Y)	Regression equation	R^2
Lettuce	Yield (ton/ha)	$Y = 16.77 + 0.0522N + 0.0576P$	0.81
	Fertilizer use efficiency (%)	$Y = 20.51 + 0.02021N$	0.48
Spinach	Nitrate (mg/kg)	$Y = 1119.13 + 4.73N$	0.74

to fertilizer use efficiency (y) as Y = 16.77 + 0.0522N + 0.0576P (R^2 = 0.81) in lettuce and it had not significant relation among nitrogen and phosphorous fertilizer and fertilizer use efficiency in Spinach (Table 12). Based on we could predicted fertilizer use efficiency with nitrogen and phosphorous fertilizer use. It recommended that study was recommended biological fertilizer application and Integrated Nutrient Management in improvement of fertilizer use efficiency in lettuce and spinach.

Conclusion

Based on these results we could predicted fertilizer use efficiency (y) by model 16.77 + 0.0522N + 0.0576P (R^2 = 0.81) in lettuce (N: kg Nha^{-1} and P: kg $P_2O_5ha^{-1}$. Based on we could predicted fertilizer use efficiency that help to agricultural practice management until nitrogen and phosphorous fertilizer used suitable and avoid leaching of nitrogen in lettuce and spinach culture.

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