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Full Length Research Paper

Cumulative effects of white clover residues on the changes in soil properties, nutrient uptake, growth and yield of maize crop in the sub-humid hilly region of Azad Jammu and Kashmir, Pakistan

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White clover grows naturally all over the Himalayan regions including the hilly areas of the state of Azad Jammu and Kashmir (AJK), Pakistan. This study was conducted to investigate the effects of white clover residues alone or in combination with phosphorus (P) fertilizer on maize (*Zea mays* L.) yield, nutrient uptake and soil properties in the hilly area of AJK. Local ecotype of white clover was established over three years in the research farm and thereafter maize was grown in the same field. The treatments were: T_1 = control without amendments; T_2 = white clover; T_3 = white clover + P_2O_5 at the rate of 50 kg ha^{-1}, and T_4 = white clover + P_2O_5 at the rate of 100 kg ha^{-1}. Results indicated that white clover residues alone or in combination with P significantly increased average plant height, dry matter yield, 1000–grain weight and grain yield. Maize dry matter yield in the control plots was 4150 kg ha^{-1} which increased significantly to 8697, 9271 and 9879 kg ha^{-1} in T_2, T_3 and T_4, respectively. Similarly, the grain yield in T_2, T_3 and T_4 was 5236, 6232, 8696 kg ha^{-1} as compared to 3400 kg ha^{-1} in the control plots. Addition of white clover residues and P fertilizer reduced the number of days required for tasseling and silking by 4–13 days over control. Residues also increased the NPK concentration in plant shoot causing significantly higher total uptake of NPK in maize. Averaged across treatments, the uptake of NPK by maize was 31, 8 and 53 kg ha^{-1} as compared to 9.8, 1.2 and 12.2 kg ha^{-1} in the control treatment. The residual effects of white clover on soil properties indicated a significant increase in saturation percentage (17–23%) and electrical conductivity (10–20%) whereas pH decreased by 23 units. Furthermore, organic carbon (C), total N, available P, K and CEC were higher in plots that received white clover alone or in combination with P than the control. White clover residues seemed to be valuable N source for biomass and grain production in hill farming system and their continuous use as soil amendment would enhance crop productivity and improve crop quality and soil fertility.

Key words: N uptake, pasture, plant residues, residual effects, soil nutrients.

INTRODUCTION

The mountain region of Himalaya including the state of Azad Jammu and Kashmir is presently under heavy stress on account of a large-scale exploitation for fuel-wood, timber and fodder, mismanagement of forest resources and frequent fires. As a result, forests are being cleared and converted into barren sites at an alarming rate. This anthropogenic activity in the mountain ecosystems has been accelerating in speed and scale resulting in drastic ecological changes in the region. High surface runoff, accelerated soil erosion and soil fertility depletion are the most widespread forms of land degradation resulting from such changes in ecosystem.

The replacement of forests by agroforestry systems or well-managed pastures with a dense and constant soil coverage may provide a recycling process similar to that

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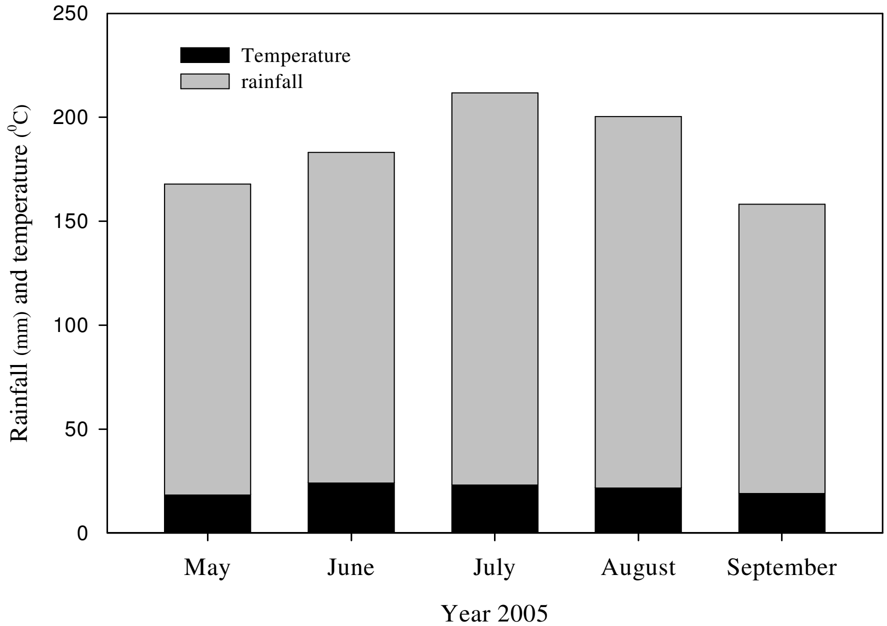

Figure 1. Monthly mean temperature (^{0}C) and rainfall (mm) of the experimental area during the growing period of maize.

of native vegetation (Serrão and Toledo, 1990), although the amount of nutrients recycled in pasture ecosystems is considerably less than in an intact forest (Serrão and Toledo, 1990). Like a forest, pasture systems store nutrients in both the living and dead biomass, and in the soil. Pastures containing legumes benefit from fixation of atmospheric nitrogen (N), and it seems that legume contents of 20–45% of herbage dry matter could provide enough N to maintain a productive and sustainable pasture (Thomas, 1992). Leguminous plant species, either growing for improved fallow (or green manures, that is, pigeonpea), economic yields (that is, peanut), or even weeds (that is, hairy indigo) are receiving considerable attention in integrated cropping systems for their ability to fix atmospheric N_2 and increase soil N availability during decomposition (Thippayarugs et al., 2008). Legumes are often grown for incorporation into soil as a green manure providing benefits such as off season soil cover, stimulated soil biological activity and improved plant nutrition. Most interest has been attached to the legume's ability to furnish subsequent crops with readily available N. However, this depends on the inherent qualities of the plant material (Amato et al., 1984), environmental factors such as soil temperature and moisture (Kladivko and Keeney, 1987) and soil type (Christensen, 1985). Besides supplying N, forage legumes also mobilize large quantities of other nutrients.

The use of white clover (*Trifolium repens* L.) has long been considered an effective way of improving pasture production and soil N status in many parts of the world. White clover grows naturally all over the Himalaya regions including the hilly regions/areas of the state of Azad Jammu and Kashmir. Keeping in view the above facts, local and exotic ecotypes of white clover were established in the hilly region at Rawalakot AJK. The forage production and N_2 fixation of both local and exotic ecotypes of white clover grown under local environment were comparable to those reported from the other parts of the world (Abbasi and Khan, 2004; Abbasi et al., 2008). For a better understanding of the effect of white clover on succeeding maize and their role in soil fertility management, it is important to quantify the amounts retained by the various sinks such as the crop and the soil. The objectives of the present study were i) to determine the effects of white clover residues on the growth and yield of following maize crop ii) to examine the effect of white clover residues on changes in major nutrient concentration in plant and soil.

MATERIALS AND METHODS

Study site, experiment description and operations

Field experiment was conducted under rain fed conditions at the experimental farm, Faculty of Agriculture, Rawalakot Azad Jammu and Kashmir (33–36°N latitude and 73–75°E longitude) during the year 2005. The topography of the area is mainly hilly and mountainous with valleys and stretches of plains. The study area is characterized by a temperate sub-humid climate with annual rainfall ranging from 500 to 2000 mm (depending on season), most of which is irregular and falls as intense storms during the monsoon and some times in winter. The monthly mean temperature and rainfall during the experiment is presented in Figure 1. Mean annual temperature is about 25^{0}C (maximum) in summer while winter is fairly cold with temperature ranging even below freezing point. Detailed characteristics of the site were previously described in our study (Abbasi et al., 2008). The soil at the site has a medium deep profile. The proper soil classification is not carried-out so far. Soil samples from 0–15 cm layer were collected from the experimental plots just before sowing, air dried and passed through a 2-mm sieve. The soil was silt loam in texture containing sand, silt and clay at the rate of 250, 520, and 230 g kg^{-1}, respectively, pH in water (1:2.5) 7.3, organic C 5.7 g kg^{-1}, total N 0.49 g kg^{-1}, available P 7.8 mg kg^{-1}, available K 98 mg kg^{-1}, and cation exchange capacity (CEC) 18.1 cmol (p) kg^{-1} soil. The soil possessed a high water storage capacity and was moderately well drained. Before the beginning of the study, the experimental site had been under horticultural cropping for more than 10 years, with a conventional management practices fertilized with chemical fertilizers each year and application of farmyard manure (FYM) once or twice during this period.

The total field area used in the experiment area was 260 m^2, out of which (15x13 m^2) 195 m^2 was brought under white clover (*T. repens* L.) cultivation for three years. On the either side of white clover plots ample space was left which was used as control for comparison. The first cut of white clover was performed at the end of April 2005. After 7–10 days interval, field was ploughed with tractor and the plant materials (root, shoot) were well incorporated into the soil. The field was left as such for next two weeks and thereafter, soil was thoroughly mixed by ploughing several times with tractor. For proper seed bed preparation, field was well leveled before sowing. The net plot size was 2×3 m^2 which was kept according to the size of the field. Similarly, control plots were also prepared accordingly in the same field designate as control.

The treatments were as follows: T_1= control without amendments, T_2= white clover (WC) residues, T_3= WC residues+ 50 kg P_2O_5 ha^{-1}, T_4 = WC residues +100 kg P_2O_5 ha^{-1}; maize varieties = 02; V_1=Sawan−3, V_2=Rafhan−2310. The treatments were replicated four times in a Randomized Complete Block Design (RCBD).

Seeds of two maize varieties were collected from National Agriculture Research Centre, (NARC) Islamabad. Phosphorus was applied in the form of single super phosphate (SSP). Fertilizer was mixed and incorporated well into the soil before sowing. Maize was sown in lines on May 26, 2005. After germination the plant to plant distance was maintained at 23 cm while row to row distance was 60 cm and a total of four rows per plot were maintained. All standard local cultural practices were followed when required throughout the growth period. Experimental plots were kept free from weeds by hand hoeing. The morphological characteristics of the crop like plant height, days taken to tasseling, and days taken to silking were recorded in standing crop. At maturity the crop was harvested at ground level during the 3rd week of September 2005. The cobs were removed from the plants and allowed to sun drying for one week. The plants from each plot were tied up into bundles for their fresh weight. Later on, they were allowed to sun drying on their respective plots for about two weeks. Thereafter, dry matter yield was recorded. Similarly, cobs were sun drying and then air drying in the laboratory for about 30 days period. Grains were separated from the pith by beating the cobs manually and grain weight per plot and 1000-grain weight was recorded. Normal standard procedures were used for the recording of the above mentioned observations.

Soil and plant analysis

In order to determine the effect of white clover residues on the changes in major nutrient contents of soil and plant, soil and plant samples were collected after harvesting. Soil samples from the 0–15 cm depth were collected from each plot, mixed well and air dried for 2–3 days. Samples were lightly ground and subsequently sieved through a 2-mm mesh to remove stones, roots and large organic residues. Soil organic carbon was determined by oxidizing organic matter in soil samples with $K_2Cr_2O_7$ in concentrated sulphuric acid for 30 min followed by titration of the excess of $K_2Cr_2O_7$ with ferrous-ammonium sulphate (Nelson and Sommers, 1982). Total N was determined by sulphuric acid digestion using Se, $CuSO_4$ and K_2SO_4 as catalyst. Nitrogen in the digest was determined by Kjeldahl distillation and titration method (Bremner and Mulvaney, 1982), available P by the Olsen extraction method (Olsen and Sommers, 1982) and available K was extracted with 1 N ammonium acetate, adjusted to pH 7 and was determined by flame photometer (Simard, 1993). Cation Exchange capacity (CEC) of the soil was determined by leaching the soil with KCl followed by extraction of exchangeable K^+ by ammonium acetate (Rhoades, 1982). K^+ in solution was determined by flame photometer. Electrical conductivity was determined on a saturation extract.

For plant analysis, the maize shoots of five plants from the central rows were sampled randomly from each plot. The samples (stalk + leaves only) were washed, cleaned, air dried and then oven dried at 65^0C to a constant weight. The oven-dried samples were ground to pass through a 4-mesh sieve in a Micro Wiley Mill. The N content in plant samples was determined by the Kjeldahl method (Jackson, 1962). The samples were digested with perchloric acid and nitrate acid, and their P concentration was determined colorimetrically (Murphy and Riley, 1962). The potassium concentration in plant samples was determined by flame photometer according to Winkleman et al. (1990).

Statistical analysis

For the determination of significant effect of treatments on the growth and yield of crop and on soil and plant characteristics, analysis of variance (ANOVA) and least significant difference (LSD) tests among means were conducted for each character separately using a MSTAT-C statistical analysis package. Comparison of means for the individual treatments was done at the 5% probability level based on the F-test of the analysis of variance (Steel and Torrie, 1980).

RESULTS

Effect of soil amendments on days taken for tasseling and silking

White clover incorporation and P fertilization in soil significantly reduced the number of days required for tasseling and silking (Table 1). Average across treatments, the maximum number of days taken for tasseling (93.8) and silking (96.5) were recorded in the control treatment while the minimum number of days taken for tesseling (81) and silking (83.5) were recorded in treatment (T_4) where higher rate of P (100 kg P_2O_5 ha^{-1}) was applied in combination with clover. Results indicated that number of days required for tasseling and silking decreased with an increase in the P rates/concentration. The number of days until tasseling and silking of maize in the clover treatment without P application (T_2) was significantly different (higher/more) from those in T_3 and T_4, but significantly lower than the control. However, addition of clover reduced the number of days relative to control (T_1). On average, two varieties did not show any significant difference.

Table 1. Number of days until tasseling and silking of maize affected by white clover cultivation and P fertilization.

Treatment	Tasseling (days)			Silking (days)		
	V_1	V_2	mean	V_1	V_2	mean
T_1	94.3a	93.3a	93.8a	97.0a	96.0a	96.5a
T_2	88.0bc	90.3ab	89.1b	93.3b	92.5b	92.9b
T_3	86.0bc	85.0c	85.5c	88.5c	87.3c	87.9c
T_4	81.5d	80.5d	81.0d	83.8c	83.3d	83.5d
mean	87.5 NS	87.3 NS	—	90.6 NS	89.8 NS	—

T_1, Control without white clover and P fertilization; T_2, white clover; T_3, white clover + P fertilizer at 50 kg P_2O_5 ha^{-1}; T_4, white clover + P fertilizer at 100 kg P_2O_5 ha^{-1}; V_1, Swan–3; V_2, Rafhan–2310.
Mean in the column followed by different letters are significantly different at P≤ 0.05.

Table 2. Residual effect of white clover cultivation and P fertilization on height and dry matter yield of maize.

Treatment	Plant height (cm			Dry matter yield (kg ha^{-1})		
	V_1	V_2	mean	V_1	V_2	mean
T_1	106.7a	149.3a	128.0a	3733e	4567e	4150d
T_2	165.7bc	191.1ab	178.4b	8516d	8878c	8697c
T_3	169.1bc	193.6c	181.3c	8855cd	9687b	9271b
T_4	170.6d	202.2d	186.4d	9807ab	9951a	9879a
mean	153.0 NS	184.1 NS	—	5276b	5611a	—

T_1, Control without white clover and P fertilization; T_2, white clover; T_3, white clover + P fertilizer at 50 kg P_2O_5 ha^{-1}; T_4, white clover + P fertilizer at 100 kg P_2O_5 ha^{-1}; V_1, Swan–3; V_2, Rafhan–2310.
Mean in the column followed by different letters are significantly different at P≤ 0.05.

Effect of soil amendments on maize biomass yield

Effect of white clover residues on the morphological development of maize is presented in Table 2. Addition of white clover alone or with P fertilizer significantly (P≤0.05) increased plant height, and dry matter yield of the following maize crop. Plant height increased by 39% in T_2 while application of P with white clover further increased height by 42 and 46% over control. The difference between the amended treatments was not significant. The difference between the two varieties was significant and Rafhan-2310 had significantly taller plants than Swan-3. The dry matter yield of maize tended to increase with the addition of white clover residues and P fertilizer. The dry matter yield of maize in the white clover treatment without P (T_2) was almost double than the control while a 2.2 and 2.4 fold increase in yield was recorded in T_3 and T_4, respectively. By taking the average of two varieties, the maximum dry matter yield of 9879 kg ha^{-1} was recorded in T_4 (P at 100 kg P_2O_5 + with white clover) as compared to 4150 kg ha^{-1} in the control treatment (T_1). Dry matter yield in Rafhan-2310 was significantly higher than the variety Swan-3.

Effect of soil amendments on yield and yield attributes of maize

There were significant effects of the white clover residues and P fertilization on yield and yield attributes of the following maize crop (Table 3). Increase in number of cobs was 21–29% over control while 2–3 fold increase in 1000-grain weight was recorded in T_2, T_3 and T_4. Both number of cobs and 1000-grain weight did not affect by the change in P concentration/rates. Residual effects of white clover or P fertilizer resulted in greater grain yield than the control plots. The grain yield in the control treatment was 3400 kg ha^{-1} which increased significantly to 5236, 6232 and 6896 kg ha^{-1} in T_2, T_3 and T_4, respectively showing an increase of 54, 83 and 100% over control. Results indicated that maize yield was increased substantially in the plots where white clover was previously grown and the yield was further increased following the application of P in white clover plots. Overall, the highest yield was obtained with application of higher rate of P fertilizer (100 kg P_2O_5 ha^{-1}) in white clover plot, which was almost double the yield of the control. The two varieties showed significant difference and grain yield in Rafhan-2310 was significantly higher than (6%) the grain yield recorded for Swan-3.

Effect of soil amendments on plant N, P, K content and nutrient uptake

The N, P, K concentration in plant shoot varied among different treatments (Table 4). Averaged across the two

Table 3. Residual effect of white clover cultivation and P fertilization on yield and yield attributes of maize i.e. number of cobs per 100 plants; 1000 grain weight and grain yield (kg ha^{-1}).

Treatment	Number of cobs 100^{-1} plants			1000 grain weight (g)			Grain yield (kg ha^{-1})		
	V_1	V_2	mean	V_1	V_2	mean	V_1	V_2	mean
T_1	62.8f	73.7e	68.2c	116.1f	138.3e	127.2c	3183f	3617e	3400d
T_2	79.8d	86.0bc	82.9b	265.3d	299.0bc	285.2b	4994de	5478d	5236c
T_3	85,0c	88.36ab	86.6a	289.0c	322.0ab	305.5a	6157c	6307bc	6232b
T_4	86.5c	89.8a	88.1a	301.7bc	327.4a	314.6a	6749ab	7043a	6896a
mean	78.5 b	84.4 a	—	243.0a	271.7b	—	5276b	5611a	—

*T_1, Control without white clover and P fertilization; T_2, white clover; T_3, white clover + P fertilizer at 50 kg P_2O_5 ha^{-1}; T_4, white clover + P fertilizer at 100 kg P_2O_5 ha^{-1}; V_1, Swan–3, V_2, Rafhan–2310.
Mean in the column followed by different letters are significantly different at P≤ 0.05.

Table 4. Residual effect of white clover cultivation and P fertilization on shoot (stalk + leaves only) N, P and K concentration (g kg^{-1}) of the following maize crop.

Treatment	Shoot N (g kg^{-1})		Shoot P (g kg^{-1})		Shoot K (g kg^{-1})	
	V_1	V_2	V_1	V_2	V_1	V_2
T_1	28.7e	18.5f	3.7d	2.2e	30.5e	28.5e
T_2	33.5bc	31.7d	6.7c	8.0bc	64.5b	34.0b
T_3	35.2a	32.2cd	7.2c	9.0ab	71.7a	47.0cd
T_4	36.2a	33.7b	9.0ab	9.5a	68.5ab	49.2c
mean	33.4a	29.1b	6.7b	7.2a	58.8a	42.2b

*T_1, Control without white clover and P fertilization; T_2, white clover; T_3, white clover + P fertilizer at 50 kg P_2O_5 ha^{-1}; T_4, white clover + P fertilizer at 100 kg P_2O_5 ha^{-1}; V_1, Swan–3, V_2, Rafhan–2310.
Mean in the column followed by different letters are significantly different at P≤ 0.05.

varieties (Figure 2), white clover residues alone or with P fertilizer significantly (*P*≤0.05) increased shoot N, P, and K content compared to control treatment. The increase in shoot N ranged from 32.6, 33.7 and 35.0 g kg^{-1} in T_2, T_3 and T_4 over the 23.6 g kg^{-1} in the control. The difference among amended treatments was also significant and addition of P also increased N uptake by maize. Shoot P and K also showed similar response and the concentration increased with white clover residues and P fertilizer. The maximum increase in P concentration was recorded in T_4 that was 3-fold to the control. Treatment T_2 and T_3 were at par showing that P at the rate of 50 kg P_2O_5 ha^{-1} did not significantly change the P concentration in plant. The increase in K concentration due to white clover residues and P fertilizer was 2-fold over control. Likewise, the effect of P on N uptake, K concentration was also significantly increased with P application. However, the two rates of P (50 and 100 kg P_2O_5) showed similar effect and the difference between the two was non-significant.

Uptake of major nutrients, that is, N, P and K by the plant was significantly influenced by the treatments (Figure 3). The total N uptake ranged between 10 and 35 kg ha^{-1} while the uptake of P and K ranged between 1 to 9 and 12 to 58 kg ha^{-1}, respectively. Addition of white clover increased N uptake from 10 kg ha^{-1} in the control to 28 kg ha^{-1} in the white clover residues treatment (T_2). Addition of P at 75 kg ha^{-1} (T_3) with white clover did not significantly change the N concentration in plants and T_2 and T_3 were at par. However, the high rate of P (T_4) significantly (P≤0.05) increased N uptake over the remaining treatments. A similar trend was observed with respect to P and K uptake by the plants. However, the extent/rate of uptake for P and K was different from N uptake. The uptake of P was low (1–10 kg ha^{-1}) while the uptake of K was high (12–58 kg ha^{-1}). Averaged across treatments, the uptake of NPK by maize was 31, 8 and 53 kg ha^{-1} as compared to 9.8, 1.2 and 12.2 kg ha^{-1} in the control treatments.

Effect of soil amendments on changes in soil properties and soil nutrient content

Plant residues alone or in combination with P fertilizer increased (*P* ≤ 0.05) saturation percentage (SP) that is, referred to soil moisture, electrical conductivity (EC), soil organic carbon (SOC), and cation exchange capacity (CEC) of soil (Table 5). Incorporation of white clover increased SP by 17%, EC by 10%, SOC by 22% and CEC by 42% over control. Addition of P fertilizer in white clover plots significantly increased the level of these characteristics and the maximum values were recorded in T_4 except SOC. Soil pH in white clover plot (T_2) was

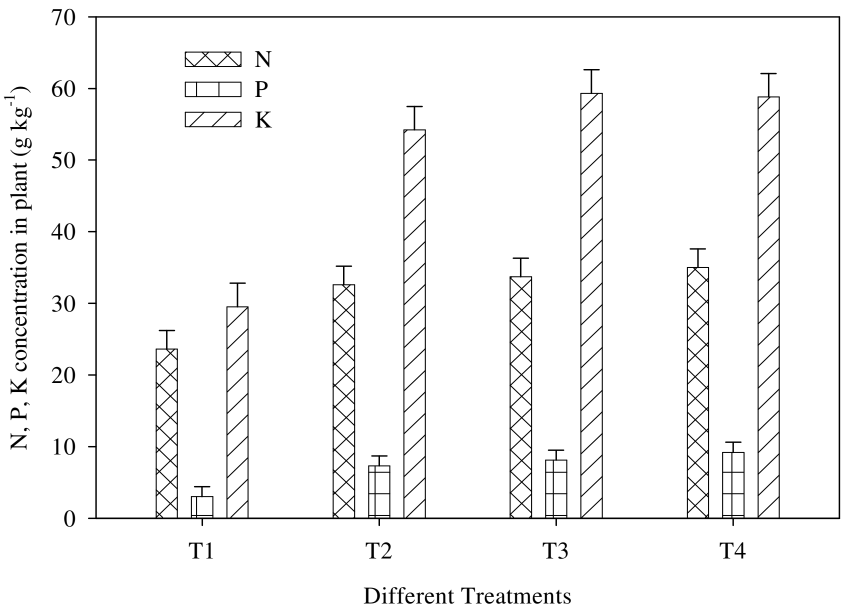

Figure 2. Shoot N, P and K concentration of maize plant (averaged across varieties) following the addition of white clover (T_2) and white clover + P fertilization (T_3 and T_4). Treatment T_1 represents the control without white clover and P fertilizer. Vertical line on each bar indicates least significant difference ($p \leq 0.05$) among NPK contents at different treatments.

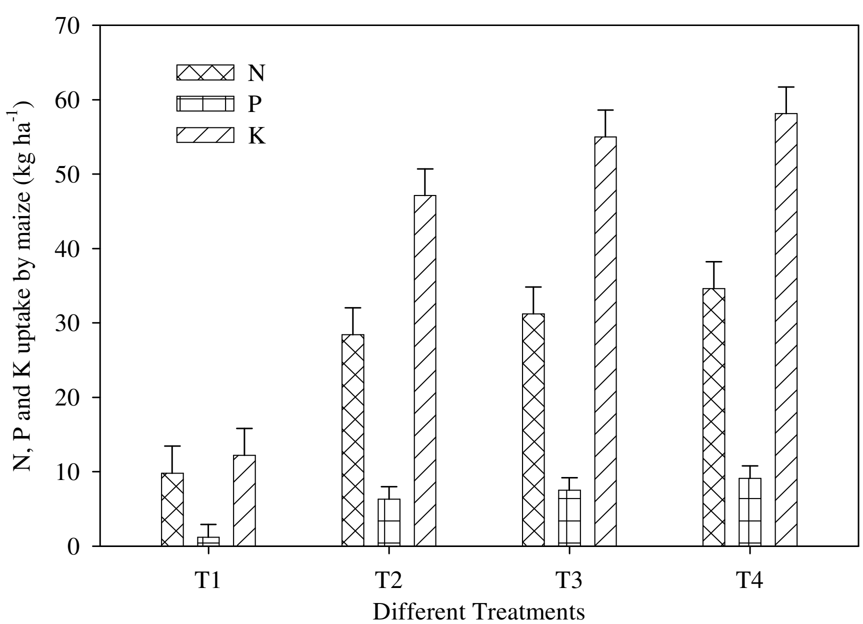

Figure 3. Uptake of N, P and K (kg ha^{-1}) by maize plant (averaged across varieties) following the addition of white clover (T_2) and white clover + P fertilization (T_3 and T_4). Treatment T_1 represents the control without white clover and P fertilizer. Vertical line on each bar indicates least significant difference ($p \leq 0.05$) among NPK uptake at different treatments.

significantly decreased relative to the control (7.26 vs. 7.49) whereas addition of P increased the pH value from 7.26 in white clover plots (T_2) and 7.49 in the control (T_1) to 7.56−7.62 in T_3 and T_4, respectively.

Table 5. Residual effect of white clover and application of P fertilizer on changes in soil properties and soil nutrient stats after the crop harvest.

Treatment	SP (%)	pH	EC (dSm-1)	OC (g kg^{-1})	N (g kg^{-1})	C:N	P (mg kg^{-1})	K (mg kg^{-1})	CEC (C mol (+) kg^{-1})
T_1	32.5c	7.49ab	0.117d	4.20cd	0.386d	11	6.51c	78.6c	124d
T_2	37.9b	7.26b	0.129c	5.19a	0.442b	12	7.96b	85.0b	176c
T_3	39.0ab	7.56a	0.140b	5.28a	0.431c	12	7.91b	91.4a	188b
T_4	40.1a	7.62a	0.152a	5.18a	0.458a	11	8.36a	94.8a	198a

T_1, Control without white clover and P fertilization; T_2, white clover; T_3, white clover + P fertilizer @ 50 kg P_2O_5 ha^{-1}; T_4, white clover + P fertilizer @ 100 kg P_2O_5 ha^{-1}; SP, saturation percentage; EC, Electrical Conductivity; OC, organic carbon; CEC, Cation Exchange Capacity.
Mean in the column followed by different letters are significantly different at P≤ 0.05.

Major nutrients i.e. NPK in the soil after harvesting maize were significantly (P≤0.05) affected by the treatments applied before planting (Table 5). The lowest N of 3.86 g kg^{-1} was recorded in T_1 (the control) which increased significantly to 4.42, 4.31 and 4.58 g kg^{-1} in T_2, T_3 and T_4 treatments, respectively. The extent of increase in N over the control in the remaining treatments was 16, 13, and 20% in T_2, T_3 and T_4. A similar trend was observed with respect to available P. The highest available P of 8.36 mg kg^{-1} was recorded in T_4, which received more P than the other treatments. On average, a 22, 22 and 28% in crease in P was recorded in T_2, T_3 and T_4 over the control. Available K was significantly higher in white clover and white clover + P treated soils than that in the control. The increase in K concentration in different treatments over control was 8, 16 and 20% for T_2, T_3 and T_4, respectively.

Correlations

The grain yield of the succeeding maize showed some correlations with the shoot DM yield (R^2 = 0.88, $p \leq 0.05$) and N uptake of maize crop (R^2 = 0.84, $p \leq 0.05$) (Figure 4). Similarly, a significant correlation was also developed between DM yield and N uptake of maize crop (R^2 = 0.94, $p \leq 0.05$).

DISCUSSION

Maize dry matter and grain yield increased with application of white clover residues and P fertilization. The increase in dry matter yield (DMY) of maize was 110−138% whereas increase in grain yield ranged between 54−103% over control. Both the parameters showed positive and significant correlation between them (r^2 = 0.88). Our results were in agreement with the result of a previous studies (Deguchi et al., 2005; Deguchi et al., 2007) in which, white clover mulch and P fertilizer increased the yield of corn compared to the no and low P application treatments. The observed increase in maize yield could be attributed to better soil physical conditions, enhanced root growth and increased nutrient capture (Baijukya et al., 2005) in addition to better soil environment for the biological activity and nutrient cycling (Arya et al., 2007). Gilbert (2000) reported that only legumes producing above 2 Mg ha^{-1}of biomass (50 kg N ha^{-1}) would be expected to provide better yield response for maize in the following season. In our previous study, the biomass production potential of local and exotic ecotypes varying from > 2 Mg ha^{-1}to 4 Mg ha^{-1} (Abbasi et al., 2008; Abbasi and Khan, 2004) showing that the white clover in our conditions is equally capable to have positive effect on the following maize crop. In the present study, the 2-fold increase in maize grain yield in white clover residues plots confirmed the superiority of white clover residues over control. However, Baijukya et al. (2005) reported that the impact of plant residues on the following crops is not necessarily from N provision as this depends on many factors including the quality of the legume biomass in terms of N release and the management of residues. Therefore, it is imperative to estimate the N mineralization potential and N releasing capacity of plant residues before applying in soil as N source.

White clover residues and P fertilizer increased NPK nutrition of the following maize crop. Nitrogen content in plants increased by 38, 43, and 48% over control whereas the extent of increase in P and K was almost double than that of N. This could be attributed to a higher N, P and K content of the white clover residues and a slow and sustained availability and release of the nutrients from organic sources with little or no losses. The N, P and K contents of the white clover incorporated in the present study were 2.29–3.0, 0.21–0.44 and 1.44–2.90, respectively (unpublished data). With regard to N, Jones et al. (1990) reported that the critical N value of corn was 25.6 g N kg^{-1} when the plant height was from 40 to 60 cm. The height of the plant at the time of analysis was almost double whereas, the N concentrations of maize shoot from all the amended treatments were over 30 g N kg^{-1} (average). Therefore, it is believed that the N nutrition of maize in the present study was sufficient in all the treatments. The concentration of P increased from 3 g kg^{-1} in control to 7.3 g kg^{-1} in white

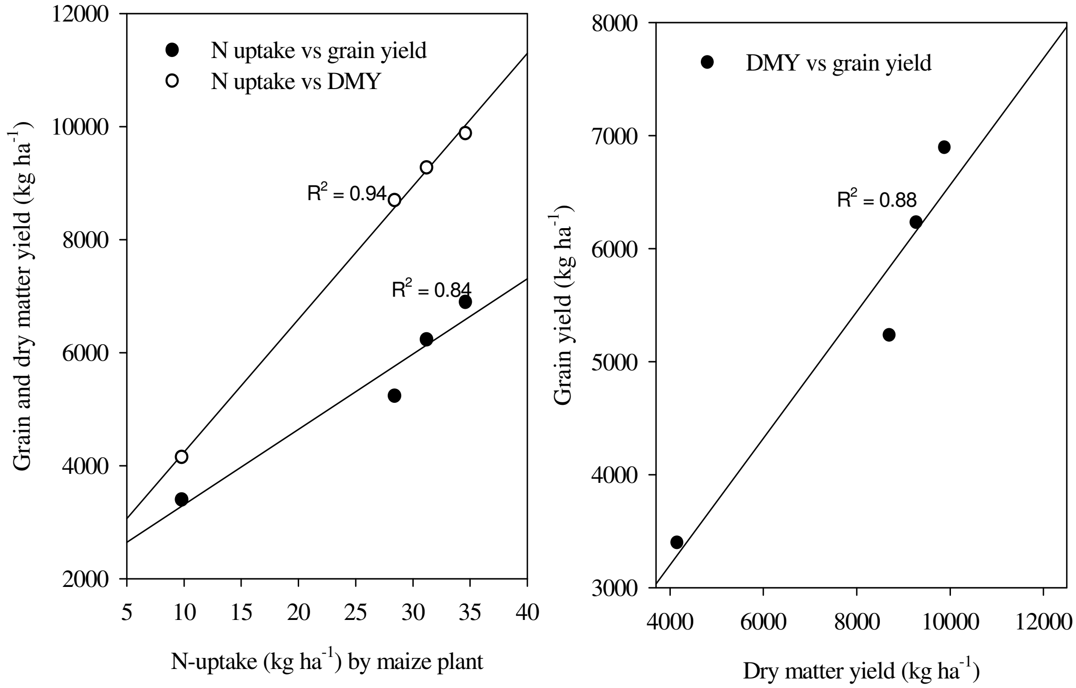

Figure 4. Correlations between nitrogen uptake by maize plant vs. gain/dry matter yield and dry matter yield vs. grain yield of maize.

clover residue treatment. Deguchi et al. (2007) reported similar results and explained that the improvement in the P nutrition of corn was not due to the biomass P of the white clover but white clover living mulch likely improved the P nutrition of corn via the AM fungus colonization of corn roots. The extent of increase in P was high in T_3 and T_4 because of the application of P fertilizer along with white clover residues.

Uptake of major nutrients by plant was significantly influenced by the treatments and nutrient uptake (NPK) was significantly greater in white clover residues and white clover+ P fertilizer plots than those without any amendments. The uptake of N by maize plant was about 10 kg ha^{-1} in the control plots (T_1) to 28, 31, 35 kg ha^{-1} in T_2, T_3 and T_4, respectively (Figure 3). Relative to control, increase in N uptake by residue treatments was very high i.e. 3–3.5 fold over control. But the comparative analysis showed that uptake in our experiment was very low as compared to those reported by Baijukya et al. (2005). The total N uptake by maize in their study ranged between 31 and 63 kg ha^{-1} in the high rainfall zone and between 45 and 94 kg ha^{-1} in the low rainfall zone. However, they used tephrosis residues along with farmyard manure in their study. In the present study, the poor nutrient uptake efficiency especially the N from the applied residues could be a result of poor decomposability of white clover residues. Baijukya et al. (2005) reported poor N uptake by maize following tephrosia residues because of high concentration of reactive polyphenols and lignin (Palm et al., 2001). Plant residues (polyphenol + lignin) with N ratio >7 [(PP + L): N ratio] are reported to decompose and release N slowly (Mafongoya et al., 1998). We did not study the above characteristics of white clover which should be considered in future study. Uptake of P by maize was relatively low as compared to N and K. The response of P in our conditions is generally low most probably because of P retention and fixation in soil. This might be a reason for low uptake of P by plants. Nutrient uptake by crops especially N and P is mostly dependent on seed yield level, which is the major sink for these nutrients. Therefore, greater productivity in residues and residues + P plots contributed to greater nutrient removal by maize plants grown in these plots. Our results clearly indicated a positive and significant correlation between N uptake vs. maize grain yield (r^2 = 0.84) and nitrogen uptake vs. DMY (r^2 = 0.94) indicating that production of dry matter and grain of maize were dependent on N uptake by maize plants. Phosphorus and potassium might also have similar relationship with the yield. Among the major nutrients, in general, K uptake was greater than N and P because of the high requirement of K by maize. In our previous study, uptake of potassium in cotton was relatively higher than N and P (Khaliq et al., 2006) and this increase in K uptake was attributed to the concentration effect which does not have any risk of loss in soil.

Soil organic carbon (SOC) concentration were increased significantly following the incorporation of white clover residues and mixing P fertilizer in these plots. The increase in C was principally due to continuous addition of C through the roots and crop residues, higher constant of the humification rate and lower decay rate (Bhattacharyya et al., 2008). Before the start of the experiment, field was covered with white clover over three years. As a result, a dense root system of white clover along with rhizodeposition was developed in these plots. In addition, during severe winter and hot summer, white clover could not persist and the whole stand of crop fell off on the soil surface. As a result, there was considerable leaf-fall biomass and plant material added in to the soil. The continuous accumulation of plant material in soil and its decaying and decomposition were collectively responsible for higher SOC content in the plots under white clover residues. Apart from that, green manuring or farm yard manure (FYM) is known to have a high humification coefficient to lead to greater C-sequestration in soil (Beri et al., 1995). The benefits of sequestering C to sustain crop productivity by applying organic amendments have been well documented in temperate regions (Aulakh et al., 2001). Therefore, the SOC accumulation rates found in this study are in agreement with previous studies that annual C inputs can result in significant increases in SOC in rain fed farming areas.

The increase in total soil N due to white clover residues is likely attributed to the positive balance of total SOC and might have been partially due to a slow mineralization or N release capacity of white clover residues that might resulted in higher total N in soil. Continuous application of inorganic N sources in soil improved the activities of micro-organisms which enhanced the transformation process in soil including the decomposition of plant residues and accumulation of N in soil (Anwar et al., 2005). White clover residues may also stimulated biological N_2 fixation in the soil, which may also have been responsible for the increase in total soil N. In addition, the residues treatments produced more crop dry matter (biomass) and, therefore, possibly had more extensive root systems that may have contributed to increased N levels. The N concentration of white clover own residues contributed towards increase in N concentration of soil. The positive SOC and total N balance illustrate the importance of long-term additions of organic materials to soil for maintaining SOC and sustaining land productivity. Such residual effects are often associated with the presence of more hydrolysable organic N in soil (Chakraborty et al., 1988). A small increase in the C/N ratio from 11 in the control to 12 in white clover treatments was also recorded. An increase in C/N ratio in the residues-amended plots might have resulted in lower microbial degradation (higher immobilization) of native soil organic matter (Bhattacharyya et al., 2008). This process could contribute an important role in improving soil physical and chemical properties as described by Bhattacharyya et al. (2008). The resulted increase in C/N ratio in the present study was rather small and certainly did not affect much on the changes in microbial activity.

Use of white clover residues also increased soil available P, and increase in P concentration was 22–28% over control. The increase in available P concentration in residues plots could be due to high microbial activity induced by the addition of organic residues which speed up P cycling (Melero et al., 2007). White clover residues tested for chemical composition showed 2.9–4.4 g kg^{-1} P as compared to 1.8 g kg^{-1} P in the grass samples (Abbasi et al., 2008). Therefore, increase in soil P might be due to the high concentration of P in white clover residues, its mineralization and accumulation in soil or possibly by increasing retention of P in soil. The retention of P in soil was further confirmed by the response of soil to the P fertilizer application in white clover plots where no increase in soil P was found for T_3 while only 5% increase in soil P was found in T_4 with high rate of fertilizer P (100 kg P_2O_5 ha^{-1}). The increased in soil P in white clover plots might also be due to the sequestration of organic matter in these plots because a strong correlation between SOC and soil P concentration existed in the present study (r^2 = 0.90). The higher concentration of available P in soil as a result of legumes cultivation or white clover incorporation, P contribution to plant uptake could last much longer time. Eghball et al. (2004) reported that accumulation of such P in soil can be significant in soils that are entirely P deficient or have P- deficient areas with in the field.

Addition of white clover increased CEC by 42% over control and this increase in CEC resulted in an increase in available K in white clover plots. Increase in CEC released more non-exchangeable K from the soils, which might have resulted in increased available K and K utilization by crops in addition to residues own K supply. The corresponding increase in K-uptake by plants indicated that solution K is removed by plants, more K is released from non-exchangeable to exchangeable and soluble pools. The increase in CEC is determined by the proportional increase in SOM content and any change in SOM directly affected the CEC of soil.

Averaged across treatments, the soil pH significantly decreased with white clover residues (T_2) over control whereas application of P slightly increased pH relative to control but significantly increased pH over T_2. In contrast, the EC of soil significantly increased by white clover residues and residues + P fertilizer. In a study carried out by Eghball et al. (2004), the residual effect of compost and manure showed an increase in both pH and EC. However, our study clearly showed acidifying effect of residues in soil. Bulluck et al. (2002) reported decreased in soil pH following the addition of organic amendments whereas Melero et al. (2007) reported only a little effect on pH values and no effect on EC after adding organic amendments in soil. Paul et al. (2001) conducted a laboratory experiment on the effect of plant residues on soil pH gradient and reported that addition of plant residue resulted in a rapid (day 0–7) increase of soil pH due to the association, and particularly oxidation, of added organic anions. This was followed by a gradual (day 7–119) pH decline attributed to the mineralization and subsequent nitrification of added organic N. Therefore, it is suggested that the effect of organic amendments on the changes in soil pH should be studied on long term basis so that the N transformation processes are completed.

Conclusion

Addition of white clover residues in soil increased the subsequent maize production and improved the fertility status of soil. The increase in dry matter and grain yield of maize with white clover addition confirmed the hypothesis that legumes are able to credit their N to the subsequent crop and are effective source of nutrients for major crops. The increase in nutrient content in soil is more encouraging in nutrient deficient soil and continuous use of white clover residues has prospects of maintaining or slowly building up SOM and increasing soil fertility. Addition of white clover residues increased the nutrient availability and uptake of N, P and K by plants increased substantially that would improve nutritional quality of maize for human consumption. Therefore, addition of white clover residues into the soil is strongly recommended for resource poor farmers incapable to use expensive input in the form of chemical fertilizers. Furthermore, interest in improving soil quality and introducing organic farming further justifies the use of plant residues especially legumes in our cropping systems.

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