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# Impact of seasonal variations and cropping systems on soil microbial biomass and enzymatic activities in slope gradient moisture stressed soils of Punjab-Pakistan

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## Abstract

*Soil biological health is one of the best indicators for soil fertility thus plays a significant role in sustainability of cropping systems. This study was designed to investigate the impact of different seasonal variations and cropping systems on soil microbial biomass and enzymatic activities in sloppy arid soils. Soil samples were collected from the sloppy soils (high, medium and low height terraces) of Khairimurat areas under wheat (Triticum aestivum)–millet (Pennisetum glaucum) and wheat (Triticum aestivum)–mung bean (Vigna radiate) cropping systems. The results revealed that the soil microbial biomass Carbon ($C_{mic}$), Nitrogen ($N_{mic}$), Phosphorous ($P_{mic}$), soil enzymes such as Dehydrogenase (DH) and Alkaline Phosphatase (AP) activity entirely depends on the soil water availability under both cropping systems at all height terraces. The wheat-mung bean cropping systems stored relatively more $N_{mic}$, $P_{mic}$, AP (activity) and less $C_{mic}$, DH (activity) as compared to wheat-millet cropping systems. Regarding the slope gradient under both cropping patterns, high height terraces had retained more $C_{mic}$ contents, medium height terraces had shown more DH activity and low height terraces had maintained more $P_{mic}$ contents. In addition to this, $N_{mic}$ contents and AP activity remained almost similar in all types of terraces under both cropping patterns. Pertaining to seasonal variations under both cropping patterns, the summer season had shown more $C_{mic}$, $N_{mic}$, $P_{mic}$, DH and AP activity as compared to spring, winter and autumn season in all types of terraces. The soil water contents increased down to depth in all types of terraces under both cropping patterns. However, soil water contents remained heterogeneous in all types of terraces under both cropping patterns. In conclusion, it is suggested that in arid environments, cover crops be included in cropping system in order to enhance soil biological health*.

**Keywords:** Cropping systems, seasonal variations, microbial biomass, enzymes activities, soil slope

## Introduction

Soil, by supplying nutrients, is the medium for the growth, development and production of crops (Brady and Weil, 2006). Various soil characteristics and biogeochemical cycles with the biotic communities influence ecosystem structure and biodiversity at different temporal and spatial scales (Holmes and Zak, 1994). Among these soil quality attributes, soil biological health is important for all nutrients needed by the plants (Kawabiah *et al.,* 2003), for sustainability of soil fertility (Smith and Paul, 1990; Lee and Pankhurst, 1992; Aslam, *et al.,* 1999) and their response against soil moisture (Shukurov *et al.,* 2005). Soil productivity primarily depends on its soil biological health, which reflects the magnitude of soil microbial biomass C ($C_{mic}$), soil microbial biomass N ($N_{mic}$), soil microbial biomass P ($P_{mic}$) and enzymatic activities (Kawabiah *et al.,* 2003; Hussain *et al.,* 2009). The soil nutrients become integral part of the crop in order to meet the grain need of the humanity under good biological health of soil (Acharya *et al.,* 2008). At present, about 60-70 percent area of Pakistan is arid to semi-arid characterized by insufficient annual precipitation to support crop production on large scale. In particular, the current cropping systems in Pothowar (arid zone of northern Pakistan) are exhaustive, instead of restorative with consequent detrimental effects on the health of soil ecosystem as well as its services and productivity.

In Pothowar tract of Pakistan, the main cropping systems adopted by farming community include wheat-fallow, fallow-groundnut, wheat-millet-lentil, wheat-millet-fallow; wheat-maize and wheat-fodder (Khan, 2001). These cropping systems (Sheikh *et al.,* 1988) and cropping practice (Huang *et al.,* 2003) in the dry land region are the main driving forces in improving soil productivity by reducing the soil erosion and maintaining the soil fertility. The main cropping system is dependent upon summer rainfall to establish winter season crops. A system known as "Dofasla" (i.e two crops in a year) is commonly practiced to store water for the following crop.

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Several researchers have reported the adverse effects of different land use practices on tropical forest, grass land and wetlands ecosystems **(**Acosta-Martínez *et al.,* 2007), appalachian forests ecosystems (Fraterrigo *et al.* 2005), streams ecosystems and on riparian ecosystem **(**Wang *et al.,* 2009). The soils of this region have poor fertility status and are less productive. Hence, this study was conducted to investigate the effects of different cropping systems on soil $C_{mic}$, $N_{mic}$ and $P_{mic}$ contents and enzymes activities in these soils and to suggest suitable cropping system under pre-existing arid climatic conditions for sustainable crop production as well as soil health.

## Materials and Methods

### Study site and soil sampling

The experimental site (Khairimurat area in Pothowar region) is geographically located at latitude [33° 34' 12"N] and longitude [72° 39' 0"E]. The climate is characterized by annual erratic rainfall ranging from 250 to 500 mm per annum and the mean annual temperature ranges from 20-25 $^{o}$C. The mean maximum temperature of the hottest month (June) goes up to 42$^{o}$C while, the mean minimum temperature of coldest month (January) ranges between 4.5 to 6.5$^{o}$C in the study areas. Broad base terraces are the most common (95%). Generally, the existing sloppy soils having high height terrace (2.13 meters above from medium height terrace), medium height terrace (1.52 meters above from low height terrace) and low terraces (0.92 meter above from the normal existing fields) which had been made by the farming community. Wheat-millet cropping system has been adopted from more than 35 years ago, while the wheat-mung bean cropping system is a newly (three years old) adopted cropping system

Eighteen (18) soil samples from each terrace of these cropping systems were collected for soil water contents during every month. These soil samples were collected up to 0-90 cm soil depth at an incremental of 15 cm soil depth. These soil samples were initially weighed in the field by digital balance along with the polythene bags. Then these soil samples were brought to laboratory every month for the determination of soil water content by gravimetric method (Hess, 1971). The soil water contents are presented in Figure 1.

For microbial biomass and enzyme activity analysis, eighteen (18) soil samples were collected from top soils (0-30 cm depth) under these cropping systems for one time in every season. These soil samples were stored in ice tubs in order to keep them frozen and then brought to laboratory for their microbial biomass and enzyme analyses. Regarding the soil physical and chemical characteristics, eighteen (18) soil samples were collected from top soils (0-30 cm depth) under these cropping systems. These soil samples were air dried, sieved and passed through sieve (< 2 mm) in order to determine soil fertility status. The soil samples were collected only once during the entire study.

### Soil physcio-chemical analysis

Soil samples were also analyzed for the soil physical and chemical properties and/or fertility status (Table 1). The soil texture was determined by Hydrometric method (Bouyoucos, 1962) and textural class was determined by method established by Gee and Bauder (1986). The soil pH, calcareousness and salinity were determined by the established methods (FAO, 1974; Page *et al*., 1982). Similarly, the total organic C, total N, available P, soluble K, soluble Na, cation exchange capacity (CEC) and Ca + Mg of the soil samples were determined by the established methods (Richards, 1954; FAO, 1974; Knudsen *et al.*, 1982; Rhoades, 1982). The experimental sites have low fertility status which needs remedial measures through fertilizer application in order to maintain soil fertility.

**Table 1: Fertility status under both cropping systems in soil profile (0-30 cm)**

| **Soil Fertility** | **Wheat-millet** | | | Wheat-mung bean | | |
|---|---|---|---|---|---|---|
| | **High** | **Medium** | **Low** | **High** | **Medium** | **Low** |
| Texture | Loam | Loam | Loam | Loam | Loam | Loam |
| pHs | 8 ±0.05 | 7.9±0.07 | 8.05 ±0.09 | 7.97 ±0.05 | 8.00±0.05 | 8.02±0.09 |
| ECe (dS $m^{-1}$) | 0.37±0.03 | 0.41±0.03 | 0.38 ± 0.03 | 0.35 ± 0.03 | 0.31 ± 0.03 | 0.34 ± 0.03 |
| CEC (meq $100g^{-1}$) | 8.3±0.56 | 6.4±0.70 | 9.95 ± 0.21 | 5.4 ± 1.13 | 7.8 ± 1.27 | 7.25 ± 3.46 |
| Total Organic Carbon (%) | 0.6±0.03 | 0.76±0.03 | 0.44 ±0.03 | 0.56 ±0.05 | 0.58 ±0.17 | 0.56 ±0.03 |
| Total Nitrogen (%) | 0.051±0.001 | 0.065±0.003 | 0.037±0.003 | 0.047±0.003 | 0.032±0.005 | 0.045±0.001 |
| Available Phosphorus (μg $g^{-1}$) | 3.85±0.63 | 4.15±0.91 | 4.65 ± 0.77 | 4.3 ± 0.84 | 4.65 ± 0.63 | 4.15 ± 0.77 |
| Soluble Potassium (meq $L^{-1}$) | 3.79±0.11 | 3.55±0.16 | 4.13±0.21 | 4.11±0.16 | 4.31±0.08 | 4.20±0.10 |
| Soluble Sodium (meq $L^{-1}$) | 2.95±0.15 | 3.68±0.32 | 2.51±0.15 | 2.94±0.76 | 2.11±0.34 | 2.43±0.09 |
| Ca + Mg (meq $L^{-1}$) | 0.38±0.03 | 0.44±0.03 | 0.40 ± 0.05 | 0.46 ± 0.08 | 0.42 ± 0.03 | 0.42 ± 0.03 |

High: High height traces ; Medium: Medium height traces; Low: Low height traces

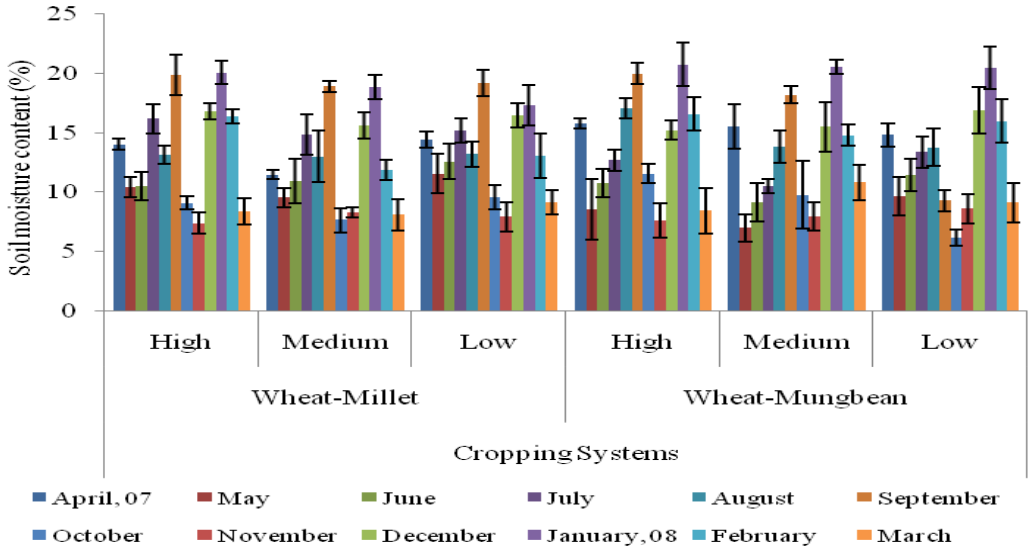



**Figure 1: Cumulative moisture content (%) in soil profile (0-90 cm depth)**

## Soil microbial biomass analysis

### *Soil microbial biomass C*

For soil microbial biomass C ($C_{mic}$), about 50 g soil sample was taken from representative sample out of which 25 g was fumigated at 25°C for 24 h with ethanol free chloroform ($CHCl_3$). The fumigant was removed before taking soil extract. The soil extract was obtained by mixing soil with 100 mL 0.5 M $K_2SO_4$ and horizontal shaking at 200 rev. $min^{-1}$ shaking for 30 minutes. Soil extract was filtered through a folded filter paper. The non-fumigated portion (25 g) also followed the same procedure. The organic carbon in the extracts was measured as $CO_2$ emission by infrared absorption after combustion at 850 °C by using a Dalmatic 100 automatic analyzer. The microbial biomass Carbon ($C_{mic}$) was calculated by using previously published method (Anderson and Ingram, 1993; Joergensen and Mueller, 1996). Microbial biomass C was calculated as follows:

Microbial biomass C = Ec / $k_{EC}$

Where Ec = (Organic C extracted from fumigated soils) - (Organic C extracted from non-fumigated soils) and $K_{EC}$ = 0.45.

### *Soil microbial biomass N*

Soil microbial biomass N ($N_{mic}$) was measured by using method developed by Brookes *et al.* (1985). The soil sample of 30 g in a 100 mL beaker containing 50 mL chloroform was placed in the desiccators. In addition, the pumice boiling granules were also added into the chloroform containing beaker to enhance rapid volatilization of the chloroform. The control non-fumigated soil samples also followed the same procedure. The vacuum was applied to the fumigated treatment during boiling. The fumigated treatment was then evacuated using a vacuum pump repeatedly (8-12 times). From the desiccators, the fumigated and non-fumigated soil samples were transferred to 250 mL Erlenmeyer flasks and 100 mL 0.5 M potassium sulfate solution was added into each sample. The samples were shaken on an orbital shaker for 1 h. Then the suspension was filtered through Whatman No. 42 paper. The filtrates were added into a 250 mL calibrated digestion tube containing 1 mL 0.2 M copper sulfate solution, 10 mL concentrated sulfuric acid and a few pumice boiling granules. Then the tubes in racks were placed in the block-digester for 3 hours. The temperature was set to 150 °C to remove extra water and was increased up to 380 °C. The tubes in racks were cooled to room temperature. The total N in the extracts was measured as $NO_2$ after combustion at 760 °C by using a Shimadzu-N chemo luminescence detector (Shimadzu Corp., Japan). The microbial biomass N was calculated as follows:

Microbial biomass N = $E_N$ / $k_{EN}$

Where, $E_N$ = (Total N extracted from fumigated soils) – (Total N extracted from non-fumigated soils) and $k_{EN}$ = 0.54.

### *Soil microbial biomass P*

Soil microbial biomass phosphorus was measured by fumigation-extraction (Brookes *et al.*, 1985) as described by Joergensen and Muller (1996). Three portion equivalent

to 5 g oven-dry soil was taken from the 50 g soil sample used for measuring the basal respiration and each was extracted with 100 mL of 0.5 M $NaHCO_3$ (pH 8.5). The first portion was used for fumigation treatment, second portion for the non-fumigation treatment and the third portion for estimating P fixation by the addition of 25 µg P $g^{-1}$ soil as $KH_2PO_4$ to the extractant. Phosphorus was analyzed by a modified ammonium molybdate-ascorbic acid method as described by Joergensen and Muller (1996). Microbial biomass P was calculated as follows:

Microbial biomass P = *E*p / ($k_{EP}$ /recovery)

where *E*p = ($PO_4$-P extracted from fumigated soil) – ($PO_4$-P extracted from non-fumigated soil), $k_{EP}$ = 0.40 (Brookes *et al.,* 1985). Recovery was calculated as follows:

1-($PO_4$-P extracted from non-fumigated and spiked soil) – ($PO_4$-P extracted from non-fumigated soil) / 25.

## Enzyme activity analysis

### *Soil alkaline phosphatase*

For the estimation of alkaline phosphatase (AP), one gram of soil sample was mixed with 0.2 mL toluene, 4 mL of MUB (modified universal buffer having pH 11) and 1 mL of *p*-nitrophenyl phosphate solution. The mixture in the flask was placed in an incubator at 37 $^0$C for 24 hours. Then 1 mL of 0.5 M $CaCl_2$ and 4 mL of 0.5 N NaOH were added into the mixture. Afterwards, the soil suspension was filtered through a Whatman No.2 filter paper. The yellow color intensity was measured at 400 nm wavelength by using a spectrophotometer (Pharmaspec UV-1700 Shimadzu, Japan) (Eivazi and Tabatabai, 1977).

### *Soil dehydrgenase*

About 0.2 g of $CaCO_3$, 1 mL of 3% aqueous solution of TTC (triphenyl tetrazolium chloride) and 2.5 mL of distilled water were added into 10 g soil sample. The samples were incubated into tubes at 37 $^0$C. Then 10 mL of methanol was added into tubes and filtered after shaking. The red color intensity was measured by using a spectrophotometer at a wavelength of 485 nm (Casida *et al.,* 1964).

## Statistical analyses

The investigations depicted are in arithmetic means and expressed on an oven dry basis (about 24 h at 105 $^o$C) only for soil water contents. In addition to this, the average of each sample for seasonal variation, soil fertility and microbial biomass were calculated and the standard deviation was tested at α 5% probability. All the statistical analyses were performed by using Stat View 5.0 (SAS Inst., Inc., USA).

## Results

## Soil microbial biomass

### *Soil microbial biomass carbon ($C_{mic}$)*

Soil microbial biomass carbon ($C_{mic}$) was monitored under wheat – millet and wheat – mung bean cropping system in Khairimurat area in summer, winter, spring and autumn seasons (Figure 2). The data pertaining to soil microbial biomass under wheat-millet cropping systems showed that it did not differ significantly ($p > 0.05$) but showed a variable trend in all seasons in all soil terraces. The average $C_{mic}$ contents differed significantly ($p < 0.05$) under wheat-mung bean cropping systems. It was significantly ($p < 0.05$) lower in autumn season as compared to other seasons. It was non-significantly ($p > 0.05$) higher in summer, winter and spring as compared to autumn season in all terraces. Data showed that under both cropping systems, its contents were available more in high height terraces as compared to medium and low height terraces in all seasons. Overall, it was available more in summer seasons as compared to all other seasons under both cropping systems. Collectively, high height terraces had maintained more $C_{mic}$ contents as compared to medium and low height soil terraces. The whole picture revealed that $C_{mic}$ contents did not differ significantly among both cropping systems and relatively wheat-millet cropping systems had maintained more $C_{mic}$ contents as compared to wheat-mung bean systems.

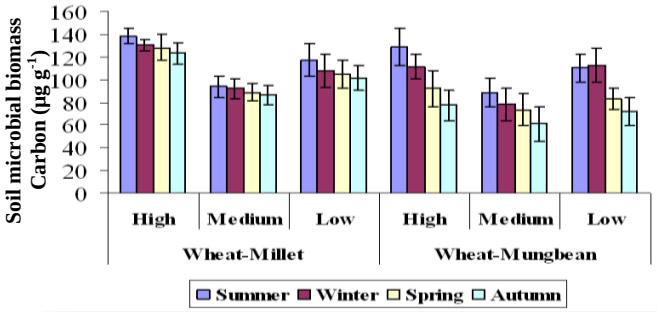



**Figure 2: Soil microbial biomass carbon (µg $g^{-1}$) under wheat-millet and wheat-mun gbean cropping systems**

### *Soil microbial biomass Nitrogen ($N_{mic}$)*

Soil microbial biomass nitrogen ($N_{mic}$) was also monitored under wheat-millet and wheat-mung bean cropping system in Khairimurat area in summer, winter, spring and autumn seasons (Figure 3). Under wheat-millet cropping systems, its contents varied little bit in all the seasons. It showed a variable trend in all the terraces and was non-significantly ($p > 0.05$) higher in summer and

winter season as compared to spring and autumn season, respectively. Regarding the slope gradient, its availability was almost uniform in all types of terraces under this cropping system.

Under wheat-mung bean cropping systems, its contents were significantly ($p$ <0.05) lower in winter, autumn and significantly ($p$ < 0.05) higher in summer and spring respectively in all terraces. Its contents were almost in uniform status in high, medium and low height terraces under this cropping system. Overall, the summer season had maintained more $N_{mic}$ contents under both cropping systems in all terraces as compared to winter, spring and autumn seasons. Relatively, wheat-mung bean cropping systems had maintained more $N_{mic}$ contents as compared to wheat-millet cropping systems.

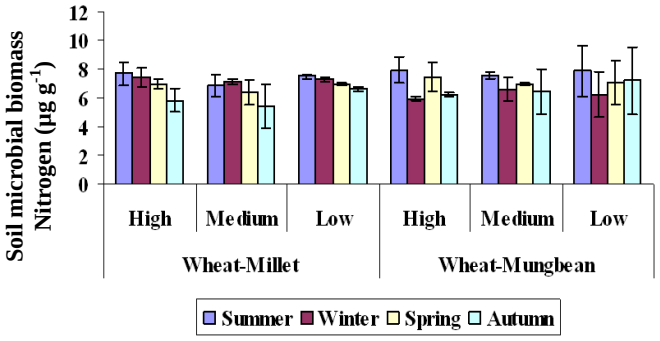



**Figure 3: Soil microbial biomass Nitrogen (µg $g^{-1}$) under wheat-millet and wheat-mungbean cropping systems**

### *Soil microbial biomass Phosphorous ($P_{mic}$)*

Figure 4 represents the soil microbial biomass phosphorous ($P_{mic}$) contents of wheat-millet and wheat-mung bean cropping system. $P_{mic}$ contents were determined in summer, winter, spring and autumn seasons from Khairimurat area. The $P_{mic}$ under wheat-millet cropping systems differed significantly ($p$ < 0.05) in all the seasons in all the terraces. It was maximum available in summer season as compared to other seasons. Relatively, low height terraces have maintained more $P_{mic}$ contents as compared to medium and high height terraces.

The $P_{mic}$ under wheat-mungbean cropping systems also showed that it differed significantly ($p$ < 0.05) in all the seasons and also in all types of terraces. In summer seasons, it was more in low terraces as compared to high and medium terraces. In winter season, its availability was higher in high height terraces as compared to medium and low height terraces. During spring and autumn seasons, it was non-significantly ($p$>0.05) higher in high and medium height terraces as compared to low terraces. The autumn season has very low $P_{mic}$ contents in low height terraces under cropping system. Overall, it was concluded that wheat-mung bean cropping systems had accumulated more $P_{mic}$ contents in summer seasons in low height terraces as compared to wheat-millet cropping systems.

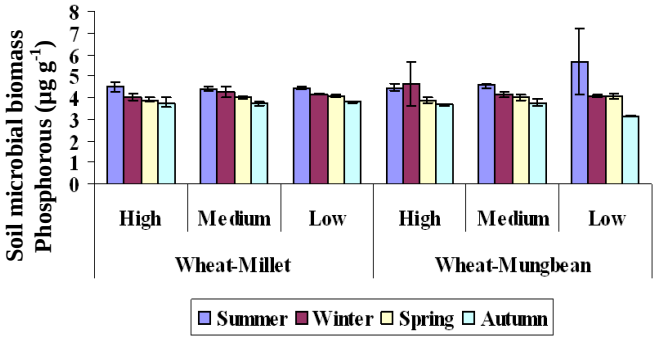



**Figure 4: Soil microbial biomass Phosphorous (µg $g^{-1}$) under wheat-millet and wheat-mung bean cropping systems**

## Enzyme activity

### *Soil dehydrogenase*

As regards the dehydrogenase (DH) activity, its data was monitored (Figure 5) during summer, winter, spring and autumn season under wheat-millet and wheat-mung bean cropping systems in Khairimurat area. Under wheat-millet cropping systems, the data showed that the average DH activity was non-significantly ($p$ > 0.05) higher in summer, winter and spring season as compared to autumn season in medium height terraces. It was significantly ($p$ < 0.05) lower in autumn as compared to summer, winter and spring season. Regarding slope gradient trend, its activity was higher in medium height terraces as compared to high and low height terraces during the summer season. Hence, its activity was high during summer season at medium height terraces and also high at low height terraces during winter, spring and autumn season under this cropping system.

Under wheat-mung bean cropping systems, the average DH activity was significantly higher in summer, season than other seasons. It was significantly ($p$ < 0.05) lower in autumn season as compared to summer winter and spring season. It also varied in all terraces in all seasons under this cropping system. In summer, its activity was high in low height terraces as compared to high and medium terraces. It was high in low terraces as compared to medium and high terraces in winter, spring and autumn season. Overall, it was concluded from the investigations that low terraces had more average DH activity as compared to other terraces under both cropping systems in all seasons. Finally, concluded that wheat-millet cropping systems had higher

DH activity in summer seasons at medium height terrace while this activity was also higher in low height terraces under wheat-mung bean cropping systems.

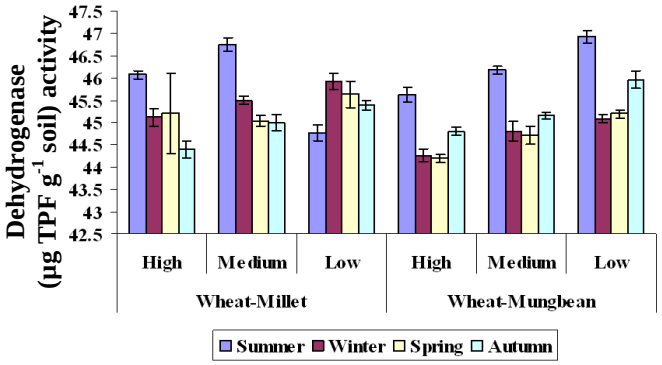



**Figure 5: Dehydrogenase (µg triphenyl formazine $g^{-1}$ soil) activity under wheat-millet and wheat-mung bean cropping systems**

### *Alkaline phosphatase*

Alkaline phosphatase (AP) activity was also estimated in summer, winter, spring and autumn seasons under wheat-millet and wheat-mungbean cropping systems (Figure 6) in Khairimurat area. Its activity under wheat-millet cropping systems showed that the average AP activity did not differ significantly ($p > 0.05$) in all the seasons in all the terraces. It almost remained uniform in all terraces. However, its activity under wheat-mung bean cropping systems differed significantly ($p < 0.05$) during all the seasons in all types of terraces. In summer seasons, it was more active in low terraces as compared to high and medium terraces. In winter season, its activity was higher in high height terraces as compared to medium and low terraces. During spring season, its activity remained almost uniform in all types of terraces. Therefore, during autumn seasons, its activity was more in high and medium height terraces and was less in low height terraces under this cropping system. Hence, wheat-mung bean had more AP activity as compared to wheat-millet cropping systems.

## Discussion

Owing to limited precipitation, an optimum soil health is essential for sustainable crop production, particularly, in arid areas. That is why it is imperative to elucidate the impact of land use including cropping system on soil health in these remote areas of the world. The magnitude of soil microbial activities/biomass, nutrients bioavailability and enzymatic activities determines the health and productivity standards of soil environment. This study was conducted to determine the impact of most commonly used cropping system (wheat-millet and wheat-mung bean) on soil $C_{mic}$, $N_{mic}$ and $P_{mic}$ contents and enzymatic activities on sloppy arid soils. The sloppy lands in the arid environment play an important role for the sustainability of the cropping systems depending upon soil fertility status and soil biological health. The soil biota is an index for soil fertility but showed a strongly direct relation with soil water availability (Khan and Joergensen, 2006).

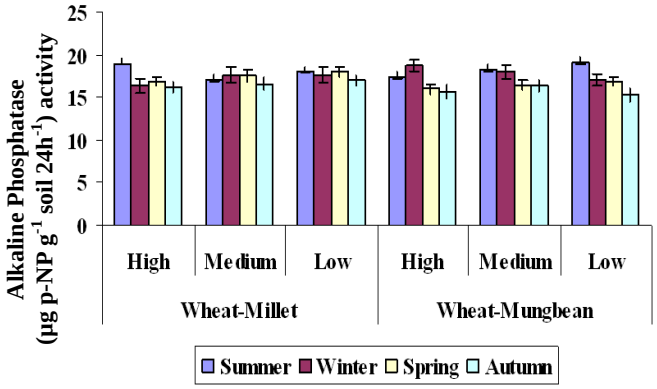



**Figure 6: Alkaline phosphatase (µg p-NP $g^{-1}$ soil 24 $h^{-1}$) activity under wheat-millet and wheat mung bean cropping systems**

Soil $C_{mic}$, as an indicator of soil quality, is largely influenced by different land use practices. Several researchers have investigated the relationship between soil $C_{mic}$ and soil prosperties like moisture (Herron *et al.,* 2009); texture (Grandy *et al.,* 2009) and rainfall (Petersen *et al.,* 2002). In our case, seasonal variations and cropping system together influence the soil $C_{mic}$ on sloppy arid soils. The $C_{mic}$ contents are mostly higher under wheat-millet cropping system in summer as compared to other seasons. This is attributable to more crop residues under this cropping system coupled with more microbial incorporation and/or decomposition in summer (Petersen *et al.,* 2002). Our results are similar to the finding of Gong *et al.* (2009) who reported addition in soil organic pool under long-term applications of manures and fertilizers under a wheat-maize cropping system in North China Plain under irrigated conditions. Similarly, Song *et al.* (2007) described an increase in $C_{mic}$ contents under inter-cropping of wheat and *Viciafaba* L. Overall, wheat – millet cropping system showed more $C_{mic}$ contents, which could be due to more crop residues production by millet compared to mung bean. Drijber*et al.* (2000), Feng *et al.* (2003) and Hamer *et al.* (2008) also showed similar finding.

Soil $N_{mic}$ is also a major source of N for microbial activities (mineralization and nutrient cycling) and possesses several other environmental implications (mineralization to inorganic forms and consequently environmental quality). The soil $N_{mic}$ contents are higher in summer seasons under wheat-mung bean cropping system

as compared to wheat-millet cropping system respectively. In general, the $N_{mic}$ contents under wheat – mung bean cropping system are higher as compared to those observed under wheat-millet cropping system. Likewise, Song *et al.* (2007) showed an increase in $C_{mic}$, $N_{mic}$ and $P_{mic}$ contents under various inter-cropping systems (wheat/faba bean, wheat/maize, and maize/faba bean). Contrarily, Wright *et al.* (2005) showed a decrease in $N_{mic}$ contents under millet and maize based cropping. Moreover, the higher contents of soil $N_{mic}$ under wheat – mung bean cropping system could be due to more fixation of atmospheric nitrogen by leguminous crops like mung bean (Saleem *et al.,* 2007). However, increase in soil $N_{mic}$ contents were not related to the DH activity which did not show any significance ($p = 0.05$) change in any of the cropping system. We suppose that the soil samples were taken after crop harvesting, therefore, we do not see any dynamics in DH activities, which primarily depends upon the root associated soil micro organisms in the pre-existing crops in the field (Saleem *et al,*. 2007). In our case, the $N_{mic}$ was available more in summer season under leguminous cropping base systems like the findings of Ross (1987), Patra *et al.* (1990), Bonde *et al.* (1998) and Hamer *et al.* (2008). In broader context, in arid regions having limited water availability, the selection of nutrient preserving and N-fixing crops (like legumes) could be best strategy to achieve the goal of sustainable agriculture as compared to nutrient exhausting crops like maize.

Similarly, soil $P_{mic}$ is a major source of plant available phosphorus as a nutrient. Its contents are more important under arid environmental conditions where soil edaphic features (pH and moisture) are not feasible for its availability to plants. The soil $P_{mic}$ contents are relatively more in summer seasons under wheat – mung bean cropping system as compared to wheat – millet cropping systems in Khairimurat area. Our results partially differed from He *et al.* (1997) who did not see any difference in $P_{mic}$ contents with seasonal variations; however the $P_{mic}$ contents were decreased in summer season at pastures dominant fields. In our case, more $P_{mic}$ could be due to more affiliation and interaction of P- phosphate solubilizing microorganisms with mung bean plants, which resulted in more soil microbial biomass phosphorus ($P_{mic}$) contents (Gaind and Gaur, 1991; Rodríguez and Fraga, 1999**;** Saleem *et al.,* 2007). Our $P_{mic}$ finding in the summer seasons also coincided with suggestions of Devin and Yadavap (2006) and Hamel *et al.* (2006). In addition, soil AP activities were relatively higher under wheat-mung bean cropping system in summer, which further supports our observation about soil $P_{mic}$ contents.

The soil biological health could be enhanced due to the application of organic amendment in the soil. If the sufficient amount of soil water content is available then the soil biota would decompose the crop residues and provide the essential nutrient to the crop growth and development. From all the discussion, study might reveal that addition of the crop residues in soil before the summer seasons would maintain the soil fertility status and would also provide the suitable environment to the soil biota for the mineralization of available crop residues.

## Conclusion

In summer season, the $C_{mic}$ content was 2.94% more than other seasons. High height terraces stored 3.51% more $C_{mic}$ contents as compared to medium and low height terraces on overall basis. Wheat-millet cropping systems had maintained 9.50% more $C_{mic}$ contents as compared to wheat-mung bean cropping systems. However, $N_{mic,}$ $P_{mic,}$ contents, DH and AP activity under wheat-mung bean cropping systems were also higher in summer season as compared to other seasons under wheat-millet cropping systems. However, we found relatively higher soil microbial biomass (N and P) contents except C and enzymatic activities under wheat-mung bean as compared to wheat-millet cropping system under arid environmental conditions. Optimum soil water availability through rainfall during water stress period would enable the soil biota to decompose the crop residues incorporated in soil. Therefore, crop residues in soil before the summer season should be incorporated to sustain the soil fertility index. Hence, our finding possesses broad implications in agricultural, ecological and soil ecosystem restoration perspectives. We suggest that leguminous crops are best viable option for sustainable soil productivity under sloppy arid condition.

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