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RESEARCH PAPER

Impact of land use and seasonal variations on soil ecosystem under arid environmental conditions

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Key Message: The microbial biomass, enzymatic activities, soil fertility and available soil water contents were evaluated between Wheat-Maize and Wheat-Mungbean cropping patterns during different seasons. Wheat-mungbean cropping patterns performed better and improved soil quality and soil health under arid environmental conditions.

Abstract: The experiments were carried out to evaluate dynamic trend of soil microbes in various seasons on existing cropping patterns on sloppy arable lands of Kahuta area. For this purpose, a series of experiments were initiated to monitor the soil biological status under wheat-maize and wheat-mungbean cropping patterns. From both patterns, soil samples were taken in summer, winter, spring and autumn seasons. The results differed significantly for soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), soil microbial biomass phosphorus (SMBP) in all seasons under wheat-maize and wheat-mungbean cropping patterns. Similarly, soil enzymes, particularly soil dehydrogenase (SDH) and soil alkaline phosphatase (SAP) activated heterogeneously in these sites throughout the year and had a significant correlation with legume containing cropping pattern than that of non-leguminous based cropping pattern. Moreover, results also revealed that the summer season restored higher soil biological dynamics (SMBC, SMBN, SMBP, SDH and SAP activities) as compared to winter, spring and autumn seasons. However, throughout the season, the SMBC, SMBN, SMBP, SDH and SAP (activity) was also related to soil water contents. Over all, SMBC and SAP activities were recorded more in wheat-maize cropping pattern. The SMBN, SMBP, SDH activity was higher in *Trititcum aestivum* L. - *Vigna radiata* L. cropping patterns. Average soil moisture contents and soil fertility status in mungbean based cropping pattern was found better. The average soil moisture contents (ASMC) was available less in maize based cropping pattern. Keeping in view the findings of this study, it is suggested that kahuta areas must include mungbean in their existing cropping patterns based on optimum nutrient availability from soil profile, appropriate soil biological health and moisture availability scenario in the arid environment.

Keywords: Arid, Enzymatic activities, Mungbean, Soil microbial biomass, Wheat

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Introduction

Soil acts as the nutrient index to sustain the crop productivity. However, the interaction of soil nutrition and soil properties in various temporal environmental conditions may affect the soil niche and soil biological ecosystem (Holmes & Zak, 1994). The soil biology trend is related to soil moisture accessibility and activities of soil enzymes. Resultantly, the nutrients become available from the soil to roots of the floras (Kawabiah et al., 2003). Soil microbial biomass being a prime feature in soil may play a pivotal and lingering role to maintain soil quality, fertility and soil ecology (Smith & Paul, 1990; Lee & Pankhurst, 1992). It is evident that soil biological health remained optimum under different types of cropping patterns. Moreover, it also improved the soil quality and fertility in non-tillage soil practices (Aslam et al., 1999). In addition to this, soil microbial biomass was better at low lying areas of sloppy lands as compared to upper sites due to optimum soil moisture availability (Shukurov et al., 2005). Simultaneously, soil productivity is also influenced by soil biological health that indicates the quantum of SMBC, SMBN, SMBP and also SDH and SAP activities (Kawabiah et al., 2003; Hussain et al., 2009a). With the advent of the green revolution, its side effects and consequently, environmental degradation has endangered the health of soil ecosystem. The preservation and sustainable utilization of the soil ecosystem services is one of key burning questions confronted to soil scientists across the globe (Hussain et al., 2009b). Different land use practices such as chemicals use, intensive cropping coupled with environmental degradation caused by use of brackish water in arid areas are the key players in reducing productivity in developing worlds (Foley et al., 2005). These phenomena could add into poverty in developing countries like Pakistan.

It has been well established in very recent studies that different cropping patterns have significant effect to the soil biological health such as soil microbial biomass and enzymatic activities (Cochran et al., 1989; Mitran et al., 2016; Li et al., 2018; Xiao et al., 2018; Hansen et al., 2019; Ren et al., 2019; Borase et al., 2020), soil quality (Beuschel et al., 2019; Hazra et al., 2019; Ren et al., 2019), soil health (Biswas et al., 2018; Bargali et al., 2019), SMBC and SMBN (Padalia et al., 2018; Bargali et al., 2019), soil bacterial and fungal communities (Ai et al., 2018) and soil chemical and biological characteristics (Aschi et al., 2017).

Other studies also explain that impact of seasonal variation improved rhizospheric properties (Neha et al., 2020), soil phosphorous (Ahmad et al., 2020), soil fertility management (Doltra et al., 2020), cropping systems diversification (Hoffmann et al., 2020), maize cropping patterns (Mutuku et al., 2020), soil productivity (Nassary et al., 2020), fertilizer use efficiency (Nielsen et al., 2018), soil quality (Omer et al., 2018) and legume crops (Smith et al., 2016). Many other studies also determined the critical influence of various land uses in woodland environment (Islam & Weil, 2000), prairie ecologies (Garnier et al., 2007), marshlands environment (Acosta-Martinez et al., 2007), appalachain plantations (Fraterrigo et al., 2005), rivulets network (Allan, 2004) and riparian biota (Wang et al., 2009). It is the dire need to determine the effect of various land uses adoption on soil ecosystem productivity in remote areas for materializing the dream of sustainable agriculture in these areas. In addition, these areas are currently an extreme food shortage and a chronic level of poverty.

The significant impact of soil moisture on spatio-temporal variability (Yetbarek & Ojha, 2020), seasonal variation (Abera et al., 2020; Sahoo et al., 2020), microbial communities (Ishaq et al., 2020), vegetation (Lian et al., 2020), rainfall distribution and cropping patterns (Yang et al., 2020) have been well documented. Contrarily, there is no significant impact of soil moisture by cover crops (de Queiroz et al., 2020) and leguminous crops (Onwonga et al., 2020). Balanced soil nutrition application had shown lingering and axial character to soil productivity. Soil productivity is a basic factor to increase crop yield which in turn becomes a linchpin of the country's economy. The variability of soil fertility in the soil might be due to application of unsuitable inputs. As the soil has a buffering capacity due to variable physiochemical characteristics. The nutritional availability depends upon many soil environmental factors such as soil moisture, pHs, aeration, biological health (respiration) and porosity. The availability of soil nutrients would be assimilated by plants from soil and production of grains to feed the human beings (Acharya et al., 2008).

These are adsorbed on the soil surface and from there the rhizoids had to be taken from the rhizosphere. Their mobility within the soil might be horizontal and vertical depending upon the soil consortia. The synergistic and antagonistic association due to various chemical bonding might lead to the availability and the deficiency pool (Rietz & Haynes, 2003). Rainfall is prime factor for the sustainability of various cropping patterns in arid to semi- arid dry land farming. In pothowar tract, usually, "Dofasla" practice is common. It means growing of two crops in one year. The entire area relies on precipitation distribution. The lands are mostly kept fallow in order to retain more rainfall water for growing of crops. Most commonly used crops such as wheat, maize, barley, millet, sorghum and rapeseed had been grown in pothowar valley. In addition to this, the rearing of animals and small ruminants are also aligned with their existing cropping patterns. It has been well known that this area had major wheat based cropping patterns in conjunction with the aforementioned crops in high, medium and low rainfall areas (Khan, 2001). Prior to this, yield pattern and cropping strength factually varied yearly due to prevailing of rainfall water availability through precipitation (Sheikh et al., 1988).

The crop management is very important in all types of agro-ecological zones. However, various types of cropping patterns such as alley cropping, relay cropping, single cropping, multiple cropping and continuous cropping had been practiced in the world. Crop rotation as a crop management factor proved to be the best option in low rainfall inception areas (Huang et al., 2003). In rainfed areas, crop yields vary significantly and direly depend on the rainfall and crop intensity. In this consequence, intrusion of any low water requirement crop such as mungbean, tomato, corn, potato, millet and sorghum on bare lands during fallow period of their existing cropping patterns would not only improve the economic condition of farming community but also endure the soil fertility (Fengrui et al., 2000). In Pakistan especially in Pothowar region, the farming community is adopting different cropping patterns. In these patterns, mostly exhaustive crops are being practiced. Therefore, the water requirement of these crops does not exist in harmony to annual rainfall. The soil fertility also depends on the cropping intensities and rainfall distribution. Unfortunately, the soils of these areas are less productive due to having low soil fertility status. Keeping in view the importance of above deliberations, a series of experiments were planned to determine the impact of land use and seasonal variations under various cropping patterns on SMBC, SMBN, SMBP and activities of SDH and SAP. Hence, this study had been therefore planned with the objective to evaluate the soil biological health and also to recommend the suitable cropping patterns depending upon the soil fertility and available soil moisture contents trends to the farming community of kahuta areas.

Materials and Methods

Experimental sites background and site selection

Regarding precipitation distribution, the Pothowar valley has been distributed to three categories such as high, medium and low rainfall parts. Islamabad, Kahuta, Murree, Kotli Sattian and Rawalpindi areas belong to high rainfall receiving areas. Medium rainfall areas are comprised of Gujjar Khan, Soi Chemian, Kalar Sydan, Kahirimurat and Fateh Jang and Qutbal vicinity. Talagang, Mianwali, Jand, Pindi Gheb, Basal and Attock areas fall in low rainfall reception tracts. In general, the high rainfall areas have rainfall almost 700-1000 mm per annum; moderate areas receive rain almost from 250-650 mm per annum and the low parts get precipitation below 250 mm per annum. For present study, experimental sites have been selected from two sites of the Kahuta area. These sites were Jagiot Khalsa and Dhupri. These areas were adopting two cropping patterns such as *Triticum aestivum* L. – *Zea mays* L. and *Triticum aestivum* L. – *Vigna radiata* L. These experimental sites are present almost 36 to 56 km away from the Rawalpindi, respectively (Fig. 1). The farming community of this area is adopting two cropping patterns such as of wheat-maize (*Triticum aestivum* L. – *Zea mays* L.) and wheat-mungbean (*Triticum aestivum* L. – *Vigna radiata* L.). Wheat-maize cropping patterns had been adopted > 20 years in pothowar valley. Wheat-mungbean cropping pattern is a young cropping pattern and this pattern has been adopted for more than 5 years. The monthly monitored rainfall data and temperature (Fig. 2) of these areas are in this way that it was more (15.69 mm) during August and less (0.0 mm) during October. However, August received higher rainfall as compared to all other months. More rainfall during August was noted due to the monsoon season. Regarding temperature data, May to August were hotter months as compared to all other months and the remaining months were less hot due to almost cool weather conditions. Hot months gained more temperature due to blowing of hot winds and cold months received low temperature due to blowing of cold winds.

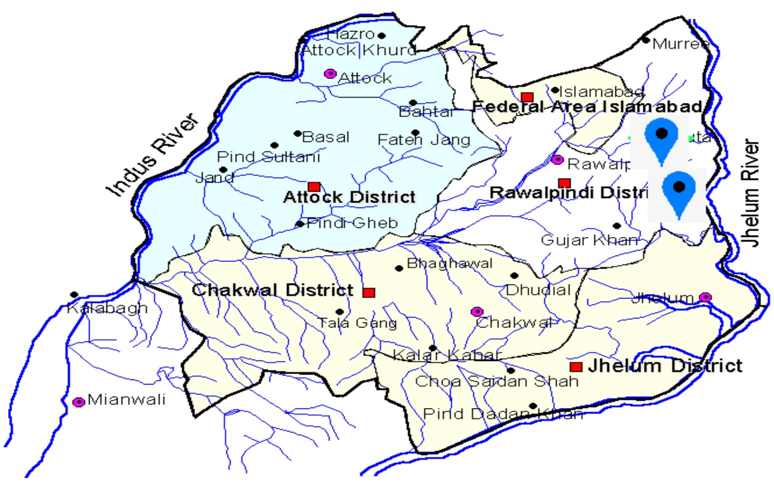

Fig. 1 Location of experimental sites for wheat-maize and wheat-mungbean cropping patterns

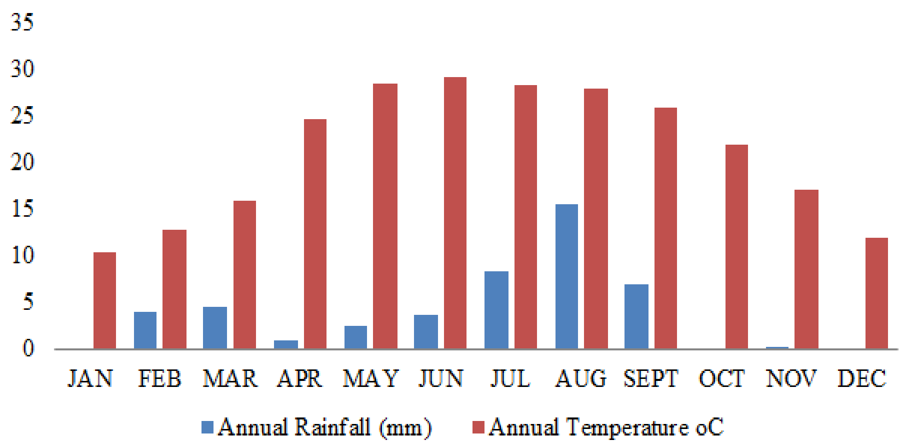

Fig. 2 Annual rainfall (mm) and temperature (^oC) patterns at experimental sites

Soil sampling collection

Soil samples from the experimental sites were collected. In this regard, eighteen (18) soil samples were taken from each cropping pattern at 0-30 cm soil depth. The cropping patterns were replicated thrice. During soil sampling from *Triticum aestivum* – *Zea mays* cropping pattern, wheat crop was present in winter, autumn and up to spring season. The maize crop was present in the field in summer seasons. While during soil sampling from *Triticum aestivum* – *Vigna radiata* cropping pattern, wheat crop was similarly present in winter, autumn and upto spring season. The mungbean crop was present in the field in summer seasons. The samples were drawn with soil augar from soil profile (0-30cm soil depth) of each cropping pattern in each season. The drawn samples were dried in open space, passed through 2 mm pore size sieves and stored in 21 polythene bags. The weight of the drawn soil sample was almost 1.5 kg in each polythene bags. The soil samples collected for soil biological health such as soil SMBC, SMBN, SMBP and enzymatic activities of SDH and SAP were stored in an ice cooler (-20°C) immediately. Moreover, the soil samples from each cropping pattern were drawn from soil profile (0-30 cm soil depth) collected with soil auger for determination of soil fertility status. These soil samples were also collected in polythene bags, marked properly and stored in major sampling bags. These samples were then brought to laboratory for estimation of soil texture, soil reaction, calcareousness, soil salinity, total organic carbon (TOC), total soil nitrogen (TN), available soil potassium (AK), soil soluble phosphorous (SP), soil soluble sodium (Na^+) and Ca^{2+} + Mg^{2+} of both cropping patterns.

Prior to this, the soil samples from each cropping pattern were collected with soil auger 0-90 cm soil depth for estimation of average soil moisture strength. The initial weight was recorded with digital balance at site, labeled and then brought to the laboratory for determination of soil water contents on an oven dry basis.

Laboratory analysis

After soil sample preparation, collected soil samples were used for analysis of soil fertility. In this regard, soil texture was determined according to Bouyoucos (1962) method. Soil textural class was estimated through triangle procedure established by international soil science society (Gee & Bauder, 1986). The electrical conductivity, pH, $CaCO_3$ was determined according to method's established by Food and Agriculture Organization [FAO] (1974); Page et al. (1982). TOC, TN, AP, K, Na^+ and Ca+Mg were estimated according to by (Food and Agriculture Organization [FAO], (1974); Buresh et al. (1982); Olsen & Sommers (1982); Knudsen et al. (1982); Richards (1954) methods, respectively in both cropping patterns in each season. Cation exchange capacity of both cropping patterns in each season was estimated by Rhoades (1982) method.

Determination of soil moisture

For the soil moisture contents determinations, first of all, samples were drawn initially at spot and their initial weight is recorded. Then, these drawn samples were taken in the laboratory for the other weight measurement. In this regard, these samples were placed in an oven at 105 °C overnight. The next day, these samples were removed from the oven. Their second weight was noted. Finally, the soil moisture contents were calculated by using the below mentioned formula. The soil moisture in soil prolife was actually estimated by gravimetric method established by Hess (1971):

$$\text{Soil moisture } \% = \frac{\text{Weight of fresh soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Soil microbial biomass and enzymes activities analyses

Soil microbial biomass carbon

For soil microbial biomass (SMBC) estimation, 50 g soil sample is taken which was a true representative sample. This sample was divided into two portions and equally divided. The sample (25 g) was used for fumigated procedure and other 25 g was for non-fumigated procedure. The fumigated sample was fumigated with ethanol free chloroform for 24 hours at 25 °C. Before extraction of sample, fumigant was removed. The 100 ml of 0.5 M K_2SO_4 was added in the sample. The sample was shaken for 30 min at 200 rev min^{-1}. After this, the soil sample extract was properly filtered through whatman 40 filter paper. The remaining non-fumigant sample was also processed similar to fumigant. The sample was run at Diatomic 100 automatic analyzer and the organic C was estimated as CO_2 radiation by IR absorption after combustion at 850 °C. The SMBC was determined according to method of Wu et al. (1998).

Soil microbial biomass nitrogen

The soil microbial biomass nitrogen (SMBN) was estimated by Brookes et al. (1985) method. In this regard, 30 g fresh sample was put in 100 ml beaker. In another beaker, 50 ml $CHCl_3$ was added. Theses beakers were placed in desiccator. Pumice granules boiling granules were placed that caused rapid vaporization of chloroform for fumigation purpose. The first desiccator is used for fumigation purpose. The second desiccator is for non-fumigated objective that is said to be control sample. The same procedure was adopted for non-fumigated sample. The fumigated sample was processed under vacuum pump till chloroform is vaporized in fumigated desiccator. The vacuum pump is applied almost more than 14 times for the proper vaporization of chloroform in fumigated sample containing desiccator. The fumigated and non-fumigated samples from these desiccators were taken into 250 ml Erlenmeyer flasks. Then 100 ml 0.5 M K_2SO_4 solutions were put in each flask. The orbital shaking was made for one hour to these samples. These samples were filtered by whatman's 40 filter papers. These filtrates were poured into digestion tubes having 250 ml capacity. Moreover, 1 ml 0.2 M CuSO4 solution, 10 ml conc. H_2SO_4 and some pumice boiling granule were mixed in them. The tubes were properly arranged in digestion block for further processing. The level of temperature from 150-380 ^{0}C was developed for removal of extra water from these samples. The digestion was completed almost in 2 to 3 hours. Lastly, these digestion tubes were cooled at room temperature. After combustion process, total nitrogen was estimated as NO_2 at 760 $^{\circ}$C through hi-tech instrumentation. The Shimadzu-N chemo luminescence detector (Shimadzu corp, Japan) was used for it determination. The microbial biomass nitrogen was calculated by using the following formula:

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

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

Soil microbial biomass phosphorus

Brookes et al. (1982) method was adopted for the determination of soil microbial biomass phosphorus (SMBP). In this technique, 30 g soil sample remained as a demonstrated sample. The sample was divided into three portions. One portion as true representative and other two portions for further processing are used. However, the 100 ml of 0.5 M $NaHCO_3$ (pH 8.5) was added in sub-sample 10 g of one portion sample. The soil extract was shaken horizontally for 30 min at 200 rev min^{-1}. The other sample having the same weight as the first portion was adopted as a recovery sample. In this regard, 25 µg P g^{-1} was used for recovery principle. However, KH_2PO_4 was added in this 10 g sample. The extract was taken and filtered. The P was estimated according to methods developed by Joergensen (1996). They determined P by modified molybdate ascorbic acid procedure. Moreover, the SMBP was estimated according to Brookes et al. (1985) methods.

Soil enzymatic activities

Soil alkaline phosphatase

In this regard, one gram soil sample is taken and mixture is developed. The mixture is developed due to addition of three substrates. First of all, 0.2 ml toluene is added in one gram soil. Secondly, 4 ml modified universal buffer whose pH ranges up to 11 was added to this sample. Lastly, one (1) ml p-nitrophenyl phosphatase solution was added to this sample. This mixture is now prepared in a flask. This mixture was placed for 24 hours at 37 ^{o}C in an incubator. After 24 hours, 1 ml 0.5 M $CaCl_2$ and 4 ml 0.5 N NaOH were then poured into it. Then, the material was filtered by using filter paper sheets. These filter papers have Whatman's No. 2 size. The extracts were run at 400 nm λ on the spectrophotometer. The SAP activity was measured at yellow color intensity by spectrophotometer (Eivazi & Tabatabai, 1977).

Dehydrogenase activity

For dehydrogenase activity, 6 g soil sample was taken and 2 g in each three test tubes. In these tubes, 0.2 g $CaCO_3$ was added. Then, 3% TTC (triphenyl tetrazolium chloride) and 2.5 ml deionized water were added in the samples. These samples remained under incubation at 37 ^{0}C for some time. Afterwards, 10 ml methanol was also poured into samples. The samples were shaken horizontally for 30 min. These extracts were filtered for further process. These samples were run on a spectrophotometer at 485 nm λ and red color intensity was noted for soil dehydrogenase activity (Casida et al., 1964).

Statistical analysis

The soil moisture data was noted on an oven dried basis and their arithmetic means were expressed for interpretation. The microbial biomass, soil fertility and seasonal variation results were also presented in arithmetic means and average of each sample for each aspect. The standard deviation for all of them was done by Stat View 5.0 (SAS Inst., Inc) (Steel et al., 1997).

Results

Soil microbial biomass carbon

The SMBC was monitored under *Triticum aestivum* L. – *Zea mays* L. and *Triticum aestivum* L. - *Vigna radiata* cropping patterns in each season (Fig. 3). The data depicted that SMBC values varied significantly in each season under *Triticum aestivum* L. – *Zea mays* L. cropping pattern. Average SMBC values pertaining to *Triticum aestivum* L. - *Zea mays* cropping were observed in this way that it was 155.8 µg g^{-1} during summer season, 136.3 µg g^{-1} during winter season, 130.0 µg g^{-1} during spring season and remained 140.4 µg g^{-1} during autumn season. However, wheat-maize (*Triticum aestivum* L. - *Zea mays)* cropping patterns had significantly added more average SMBC during summer season than to any other season. In addition to this, the average SMBC of *Trtitcum aestivum* L. – *Vigna radiata* L. cropping pattern was in this way. This pattern accumulated 132.1 µg g-1 SMBC during summer season, winter season restored 137.5 µg g-1, spring season added 121.0 µg g-1 and autumn season maintained 145.9 µg g^{-1} SMBC.

Under *Triticum aestivum* L. - *Vigna radiata*, the SMBC was available less significantly during spring season but non-significantly more during rest of seasons. Therefore, the SMBC availability trend was analogous to *Triticum aestivum* L. – *Zea mays* cropping patterns. In general, the *Triticum aestivum* L. - *Zea mays* cropping pattern had more SMBC during summer and *Triticum aestivum* L. - *Vigna radiata* cropping patterns had stored more SMBC during autumn season. Collectively, the Wheat-Maize cropping patterns had performed better for addition of more average SMBC contents than to wheat-mungbean cropping patterns.

Soil microbial biomass nitrogen

The SMBN data (Fig. 4) elucidated that it also varied significantly under both patterns of each season. The results depicted that SMBN under *Triticum aestivum* L. - *Zea mays* were 7.9 µg g^{-1} in summer, 6.15 µg g^{-1} in winter, 7.3 µg g^{-1} in spring and 7.01 µg g^{-1} in autumn season. It was significantly less during winter and more during spring season than to each season. However, SMBN was accumulated less during spring times than to other spells under *Triticum aestivum* L. - *Vigna radiata* cropping patterns. The SMBN in this pattern was present in this trend that it was higher accumulated more (8.54 µg g^{-1}) during summer season, remained better (7.37 µg g^{-1}) in winter times, less (5.83 µg g^{-1}) during spring period and optimum (6.72 µg g^{-1}) in autumn season. In general, the SMBN was gathered more in summer and less in spring season in wheat-mungbean cropping patterns, respectively. Comparatively the *Triticum aestivum* L. - *Vigna radiata* performed better and restored more SMBN than to *Triticum aestivum* L. - *Zea mays* cropping pattern.

Soil microbial biomass phosphorus

The results show that SMBP also differed significantly under wheat-maize and wheat-mungbean cropping patterns in each season (Fig. 5). The SMBP average values of *Triticum aestivum* L. - *Zea mays* was 5.84 µg g^{-1} during summer season, 3.91µg g^{-1} in winter spell, 4.42 µg g^{-1} in spring periods and 4.11 µg g^{-1} in autumn season. The results also had shown that it was non-significantly less during winter than to each season. Analogously, the SMBP average value was 6.12 µg g^{-1} during summer season, 5.42 µg g^{-1} in winter spice, 4.38 µg g^{-1} in spring season and 3.13 µg g^{-1} in autumn season. However, it was added higher significantly in summer spice than to the rest of the seasons. In conclusive, *Trtitcum aestivum* L. – *Vigna radiata* L. added more SMBP than to *Triticum aestivum* L. – *Zea Mays* L. cropping pattern.

Soil dehydrogenase activity

The data regarding SDH activity under *Triticum aestivum* L. – *Zea mays* and *Triticum aestivum* L.– *Vigna radiata* cropping pattern of each season was shown in Fig. 6. The average values of SDH activities were 45.01 µg TPF g^{-1} during summer season, 43.3 µg TPF g^{-1} during winter season, 43.67 µg TPF g^{-1} in spring season and 43.15 µg TPF g^{-1} during autumn season under *Triticum aestivum* L. - *Zea mays* cropping pattern. Its activity did differ significantly in this cropping pattern during each season. Prior to this, the SDH activity was observed significantly more during summer season but remained less non-significantly during winter to autumn under *Triticum aestivum* L. - *Vigna radiata* cropping pattern of kahuta area. As a whole, the average values of SDH activities remained 45.30 µg TPF g^{-1} during summer season, 44.2 µg TPF g^{-1} during winter season, 44.04 µg TPF g^{-1} during spring season and 43.92 µg TPF g^{-1} during autumn season under *Triticum aestivum* L. - *Vigna radiata* cropping array.

Soil alkaline phosphatase activity

The SAP activity was monitored under *Triticum aestivum* L. – *Zea mays* L. and *Triticum aestivum* L. - *Vigna radiata* cropping pattern (Fig. 7). The SAP activities differed significantly in these patterns to each season. The results interpretations were in this way that the average values of SAP activity was 21.8 µg p-NP g^{-1} soil 24 h^{-1} during summer season, 16.6 µg p-NP g^{-1} soil 24 h^{-1} during midwinter season, 18.9 µg p-NP g^{-1} soil 24 h^{-1} during spring season and 17.8 µg p-NP g^{-1} soil 24 h^{-1} during autumn season under *Triticum aestivum* L. – *Zea mays* cropping pattern. Hence, its activity was profound non-significantly less during winter than to other seasons under *Triticum aestivum* L. – *Zea mays*. Moreover, the average values of SAP activities were 23.9 µg p-NP g^{-1} soil 24 h^{-1} during summer season, 19.8 µg p-NP g^{-1} during winter season, 20.0 µg p-NP g^{-1} soil 24 h^{-1} during spring season and 17.4 µg p-NP g^{-1} soil 24 h^{-1}during autumn season under *Triticum aestivum* L. - *Vigna radiata* cropping pattern of kahuta area. The data suggested that SAP activity under *Triticum aestivum* L. - *Vigna radiata* cropping pattern significantly was more in summer and less in other seasons.

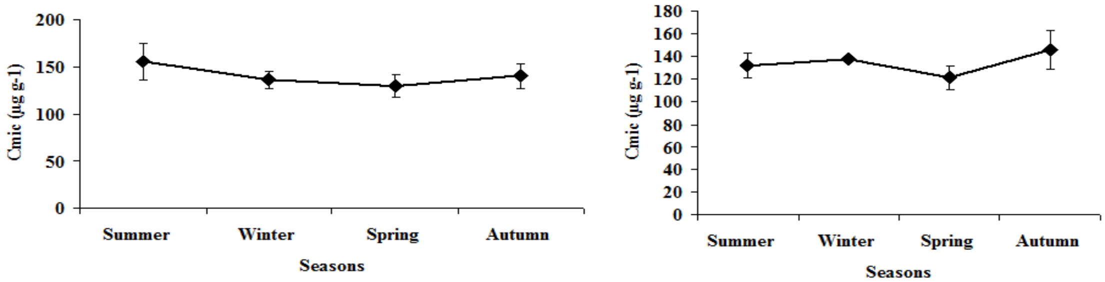

Fig. 3 Soil microbial biomass carbon (µg g^{-1}) under *Triticum aestivum* L. – *Zea Mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns in all seasons

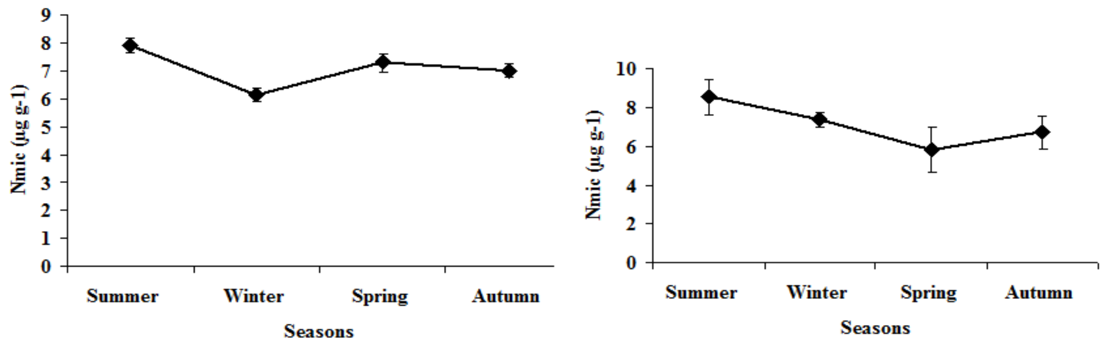

Fig. 4 Soil microbial biomass Nitrogen (µg g^{-1}) under *Triticum aestivum* L. – *Zea Mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns in all seasons

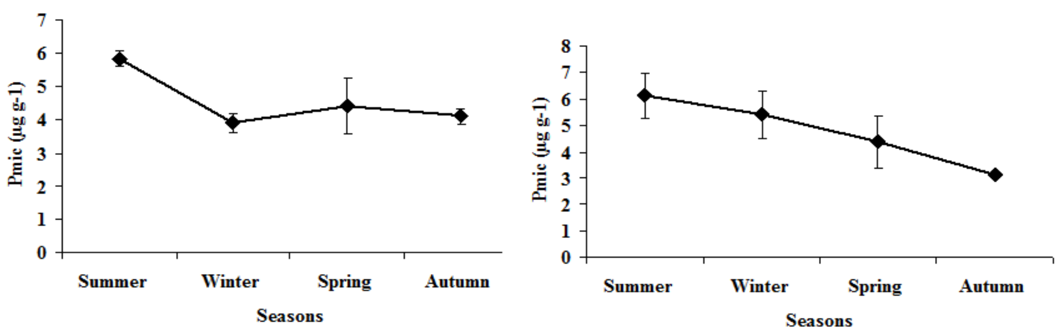

Fig. 5 Soil microbial biomass phosphorous (µg g^{-1}) under *Triticum aestivum* L. – *Zea Mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns in all seasons

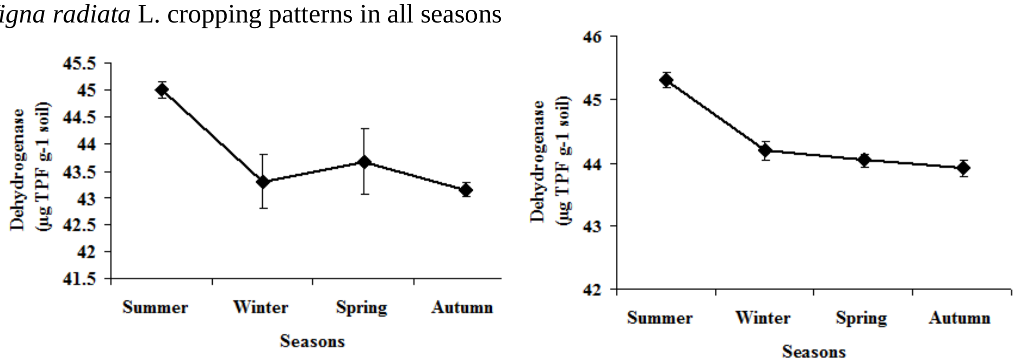

Fig. 6 Dehydrogenase (µg TPF g^{-1} soil) under *Triticum aestivum* L. – *Zea Mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns in all seasons

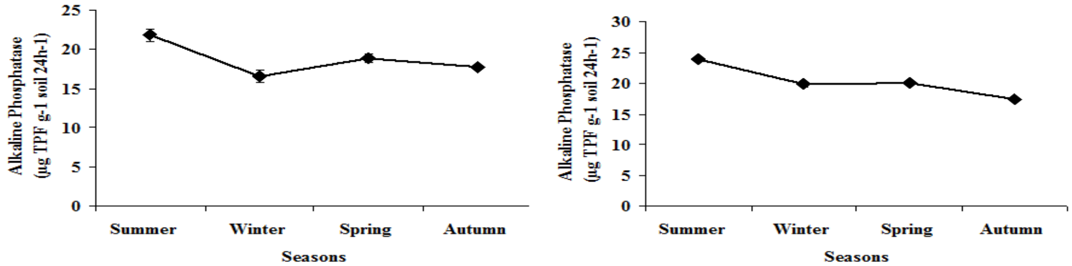

Fig. 7 Alkaline phosphatase (µg p-NP g^{-1} soil $24h^{-1}$) under *Triticum aestivum* L. – *Zea Mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns in all seasons

Soil fertility status

Plough layer fertility data of wheat-maize and wheat-mungbean cropping patterns was tabulated in Tables 1 & 2. All plough layer fertility attributes were significantly different among each other during all seasons in all sites. The data of soil fertility of wheat-maize cropping pattern exhibited in this way (Table 1). The soil texture was sandy loam in *Triticum aestivum* L. - *Zea mays* cropping pattern. The top soil had alkaline and non-saline characteristics in all seasons. The mean electrical conductivity strength was 03.2 to 0.36 dS m^{-1} and cation exchange capacity ranged from 9.8 - 14.47 meq $100g^{-1}$ soil in all the seasons. Similarly, the mean values of calcium carbonates, total organic carbon and total nitrogen ranged from 6.95-9.4%, 0.14 - 1.01% and 0.026 - 0.06%, respectively in all the seasons. Mean values of available P ranged from 2.45 - 4.65 µg g^{-1} in all seasons. The mean values of solubleK, Na and Ca^{2+} + Mg^{2+} ranged from 1.72 - 2.85, 3.01 - 6.64 and 0.33 - 0.53 meq L^{-1}, respectively in all the seasons.

The soil fertility data under wheat-mungbean cropping responded in this trend that soil texture was sandy clay loam in *Triticum aestivum L.* - *Vigna radiata* cropping pattern in all seasons (Table 2). The soil was alkaline and non-saline in nature in all seasons. The mean electrical conductivity contents were 0.26 to 0.38 ds m^{-1} and cation exchange capacity ranged from 8.56 - 12.2 meq $100g^{-1}$ soil in all the seasons. Similarly, the mean values of calcium carbonates, total organic carbon and total nitrogen ranged from 4.4 - 7.07%, 0.26 – 0.46% and 0.020 - 0.046 %, respectively in all the seasons. Mean values of available P ranged from 3.38 – 5.95 µg g^{-1} in each season. The mean values of soluble K, Na and Ca^{2+} + Mg^{2+} ranged from 3.15 - 4.61, 2.2 - 2.01 and 0.35 - 0.51 meq L^{-1}, respectively in each season. Generally, the plough layer has non-saline and alkaline properties due to possessing less EC_e and Na^+ contents in all cropping patterns to each season. Calcareousness was predominant property due to maximum deposition of Ca^{2+}. Adequate to sufficient level of TOC, TN and K^+ was present in the plough layer to each cropping pattern. The wheat-mungbean cropping patterns gathered higher levels of clay in their texture as compared to wheat-mungbean cropping patterns. It has been well known scientifically that cation exchange capacity explains the optimum availability of soil nutrients to crops from soil solution. On a site specific basis, all seasons responded to the nutrient status in this way that *Triticum aestivum* L. – *Zea mays* L. had restored higher nutrients level in soil profile than to *Trtitcum aestivum* L. – *Vigna radiata* L. In conclusion, wheat-mungbean performed better for maintenance of soil nutrients levels than to wheat-Fodder cropping pattern in all patterns but remained better in the winter season. This might be due to maximum restoration of soil nutrition by cover crops like mungbean.

Table 1 Mean values of soil quality of their 10 attributes under 1 cropping pattern in 4 seasons of Kahuta area

Cropping Pattern	Wheat-maize at Kahuta site			
	Seasons			
Soil Parameters	Summer	Winter	Spring	Autumn
Texture	Sandy Loam			
pHs	7.32 ± 0.10	7.39 ± 0.028	7.43 ± 0.03	7.8 ± 0.03
ECe (dS m^{-1})	0.36 ± 0.03	0.33 ± 0.021	0.32 ± 0.02	0.35 ± 0.01
CEC (meq $100g^{-1}$)	9.8 ± 1.55	14.47 ± 0.62	13.65 ± 0.21	10.21 ± 2.40
$CaCO_3$ (%)	9.4 ± 0.98	8.3 ± 0.84	7.9 ± 0.28	6.95 ± 0.30
TOC (%)	1.01 ± 0.12	0.64 ± 0.042	0.545 ± 0.06	0.14 ± 0.01
TN (%)	0.08 ± 0.01	0.052 ± 0.001	0.075 ± 0.006	0.026 ± 0.0007
AP (µg g^{-1})	4.65 ± 0.77	5.15 ± 0.35	4.40 ± 0.99	2.45 ± 0.19
Soluble K (meq L^{-1})	2.53 ± 0.03	2.67 ± 1.19	2.85 ± 0.23	1.72 ± 5.52
Soluble Na (meq L^{-1})	3.46 ± 0.04	3.31 ± 1.62	3.01 ± 0.11	6.64 ± 1.20
Ca ± Mg (meq L^{-1})	0.37 ± 0.03	0.35 ± 0.042	0.33 ± 0.03	0.53 ± 0.06

± mean values range that is significantly different from one another at P ≤ 0.01 using standard deviation (SD). pHs: Soil reaction; EC_e: Electrical conductivity of saturation extract; CEC: Cation exchange capacity; $CaCO_3$: Calcium carbonates; TOC: Total organic carbon; TN: Total nitrogen; AP: Available phosphorous; K: Potassium; Na: Sodium; Ca ± Mg : Calcium plus magnesium

Table 2 Mean values of soil quality of their 10 attributes under 1cropping pattern in 4 seasons of Kahuta area

Cropping Pattern	Wheat-mungbean at Kahuta site			
	Seasons			
Soil Parameters	Summer	Winter	Spring	Autumn
Texture	Sandy Clay Loam			
pHs	6.76 ± 0.13	6.80 ± 0.014	6.87 ± 0.08	7.01 ±0.02
ECe (dS m^{-1})	0.26 ± 0.02	0.29 ± 0.03	0.29 ± 0.06	0.38 ±0.007
CEC (meq $100g^{-1}$)	8.8 ± 0.56	12.2 ± 2.53	12.09 ± 2.80	8.56 ± 0.64
$CaCO_3$ (%)	4.4 ± 1.41	4.75 ± 0.49	5.15 ± 0.78	7.07 ± 0.99
TOC (%)	0.26 ± 0.05	0.41 ± 0.03	0.46 ± 0.04	0.30 ± 0.06
TN (%)	0.02 ± 0.004	0.034 ± 0.002	0.039 ±0.003	0.036 ± 0.001
AP (µg g^{-1})	5.85 ± 0.91	5.95 ± 0.21	5.95 ± 0.21	3.38 ± 0.45
Soluble K (meq L^{-1})	3.15 ± 0.39	3.15 ± 0.36	3.17 ± 0.03	4.61 ± 0.32
Soluble Na (meq L^{-1})	2.2 ± 0.11	2.01 ± 1.83	1.97 ± 0.15	2.01 ± 0.22
Ca ± Mg (meq L^{-1})	0.38 ± 0.03	0.35 ± 0.04	0.35 ± 0.01	0.51 ± 0.15

± mean values range that is significantly different from one another at P ≤ 0.01 using standard deviation (SD). pHs: Soil reaction; EC_e: Electrical conductivity of saturation extract; CEC: Cation exchange capacity; $CaCO_3$: Calcium carbonates; TOC: Total organic carbon; TN: Total nitrogen; AP: Available phosphorous; K: Potassium; Na: Sodium; Ca ± Mg : Calcium plus magnesium

Soil moisture

In soil profile (0-90 cm soil depth), the soil moisture was observed under *Triticum aestivum* L. – *Zea mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. at Kahuta area (Fig. 8) cropping pattern. The average soil moisture contents (ASMC) under wheat-maize cropping pattern was available significantly optimum during March. The ASMC were significantly less available during April, May and June. However, it was significantly available more during July to September. The ASMC was non-significantly available less during October to February as compared to August to September. However, more ASMC were available during September (15.13%) during the wheat-maize cropping pattern. The results of this pattern were in this way that ASMC were 12.19% during March, 4.23%, 2.77% and 2.25% during April, May and June, respectively. Moreover, ASMC were 11.29% during July, 11.67% during August, 15.13% during September, 9.92% during October, 8.90% during November, 10.71% during December, 10.37% during January and 11.48% during February.

Average soil moisture contents (ASMC) under wheat-mungbean cropping pattern was obtainable significantly less during March to June than to other months. The ASMC were found significantly low during April, May and June amid other months. However, it was accumulated significantly higher during July and August as compared to April, May and June. It was significantly more in the root zone during September month and all other months have its low level. ASMC increased significantly from October to December; decreased non-significantly during January and again increased significantly during February. The availability of soil moisture was in this trend that it was 9.2%, 10.6%, 7.4%, 6.2%, 17.3%, 11.2%, 22.4%, 11.7%, 13.2%, 14.9%, 12.3% and 15.8 % during March to February, respectively. Overall, the ASMc was available more during September under both cropping seasons. Hence, wheat-mungbean cropping pattern restored more (22.4%) soil moisture while wheat-maize cropping pattern had low soil moisture in their root zone.

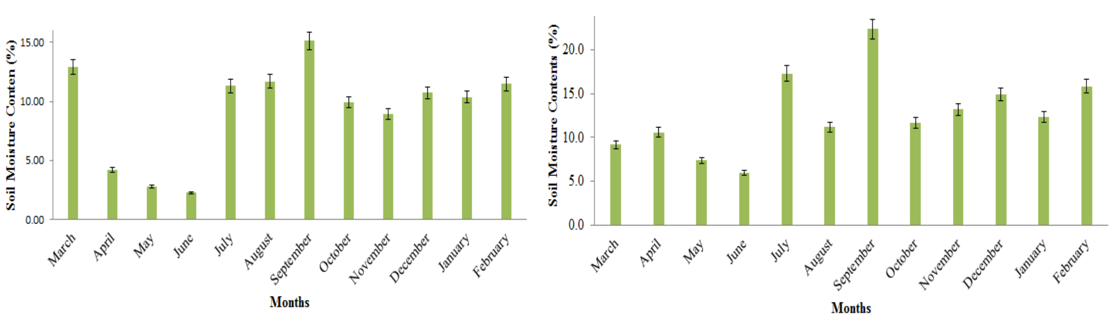

Fig. 8 Soil moisture contents (%) up to 90 cm soil depth under *Triticum aestivum* L. **–** *Zea mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. cropping patterns

Discussion

Soil health is a major and key player regarding soil productivity under arid to semi-arid environmental conditions. Simultaneously, rainfall plays a major role to enhance crop productivity to serve humanity by nature on the globe. Therefore, it is dire need of time to observe the effect of various land use having various cropping patterns on soil quality and soil health in arid to semi-arid areas of the biosphere. However, soil biological health flux such as soil microbial biomass/activities, soil fertility index such as nutrients availability may have serious concerns to quantify the soil quality and health on growth and yield in dry land farming. Therefore, it was planned to estimate the impact of existing cropping patterns such as *Triticum aestivum* L. - *Zea mays* L. and *Triticum aestivum* L. – *Vigna radiata* L. on SMBC, SMBN, SMBP, SDH and SAP at Kahuta area.

The SMBC being a soil quality precursor may be affected by various land use strategies and techniques. In this consequence, many scientists had worked on suitable and amicable relationship amid SMBC and many soil characteristics such as soil water (Ullah et al., 2009), soil temperature (Fang et al., 2005) and soil physical characteristics such as soil texture (Grandy et al., 2009). Moreover, it has been scientifically known that SMBC has been proved very critical to other practices such as use of pesticides (Hussain et al., 2009b). The present study explains that cropping patterns and seasonal variations together had significantly affected the SMBC. It was maximum under *Triticum aestivum* L. - *Zea mays* cropping pasterns during summer season. It remained lesser during winter, spring and autumn season. The greater accumulation of SMBC might be attributed to addition of more residues shredded by maize crop that might mineralize through active microbial population during summer season (Petersen et al., 2002; Williams & Rice, 2007). Contrarily, present study data (Fig. 3) under arid environmental conditions differ with the postulations given by Gong et al. (2009). According to them, admixture of various levels of fertilizer along with manuring did not significantly improve the SMBC under the same cropping pattern at irrigated agro ecosystem.

In the present case, *Triticum aestivum* L. – *Vigna radiata* had more MBC contents in autumn. These results are in opposition to Song et al. (2007) who reported enhanced levels of SMBC in *Triticum aestivum* L. – *Vicia faba* L. cropping pattern. These variations could be attributed to arid environmental conditions where crop production is solely dependent on precipitation. Overall *Triticum aestivum* L. - *Zea mays* cropping patterns had accumulated higher SMBC due to shredding of leaf and stubble residues from maize crop as compared to mungbean.

The SMBN is released through mineralization and active participation of microbes. This process would release the nutrients in the form N from the debris and also from the soil matrix to soil solution. This mechanism would enable the plants to absorb N for the growth and development system. This system would end to get the maximum yield. The average SMBN (Fig. 4) were accumulated maximum during spring and summer season under *Triticum aestivum* L. – *Zea mays* L. and *Triticum aestivum* L. - *Vigna radiata* cropping patterns, respectively. Collectively the MBN contents under *Triticum aestivum* L. - *Vigna radiata* cropping pattern were more as compared to those observed under *Triticum aestivum* L. - *Zea mays* cropping pattern. These results are different from previous findings in which authors reported decrease in microbial biomass C under *Triticum aestivum* L. cropping as compared to *Zea mays* and *Vicia faba* L cropping (Song et al., 2007). Similarly, it was also reported by Wright et al. (2005) that *Triticum aestivum* L. - *Zea mays* cropping pattern did not yield optimum the SMBN contents. Hence, the average values of SMBN were better and more under *Triticum aestivum* L. - *Vigna radiata* cropping patterns might be attributed to N-fixation from atmosphere like leguminous family such as *vigna radiata*. The higher accumulation of SMBN did not correlate positively to the SDH activities under both cropping patterns. In general, intrusion of nutrient restoration and fixation crop such as mungbean might be a viable strategy in order to sustain the agro ecosystem as compared to nutrient exhausting crops such as maize in arid to semi-arid areas.

The SMBP is also a key player and important factor for the availability of nutrients such as P from soil to crop. It is easily available where the soil pH is optimum from 5.5 to 6.5 and adequate soil moisture available but such suitable circumstances are not possible and feasible in arid to semi-arid environmental ecosystems. The average SMBP (Fig. 5) accumulated more during summer season *Triticum aestivum* L. - *Vigna radiata* cropping patterns as compared to *Triticum aestivum* L. – *Zea mays* in Kahuta area. Contrarily, it was reported by He et al. (1997) that seasonal variation did not gave significant contribution for enhancing SMBP under pastures. In their study, the SMBP were liberated less during summer seasons. In present study, the addition of SMBN might be attributed to active participation of P-solubilizing bacteria and their synergistic relation to leguminous crop like mungbean which may cause release of more SMBP contents in soil (Gaind & Gaur, 1991; Saleem et al., 2007). Moreover, The SAP activities were more in the summer season under *Triticum aestivum* L. - *Vigna radiata* cropping patterns which further support the present findings about soil MBP contents.

Ai et al. (2018) observed that stability and functionality of soil ecosystem is related to activities of soil fungi and bacteria to various land uses. The optimum levels of soil health have significantly sustained various agricultural practices. Moreover, Aschi et al. (2017) compared faba based cropping pattern. They evaluated that 1.5 times more SOC and 1.3 times more TN were accumulated in faba based cropping as compared to non-faba based cropping. The soil microbial biomass remains unchanged in these patterns. Resultantly, they suggested that induction of leguminous crops such as faba beans in their wheat possessing cropping pattern would significantly increase N and C levels in soil by maintaining the pH. These nutritional levels may ultimately respond significantly to microbial population functionalities and their community structures in such types of agro ecosystem. Hence, such rotations probably would encourage microbial activities in cultivated areas. The present results are also concomitance to their data. Similarly, Padalia et al. (2018) also postulated that forestry based agricultural fields had shown positive response on soil biological health and characteristics in arid environmental conditions. Hansen et al. (2019) suggested that canola crop has significant effects on soil microbial communities that ultimately drive microbial mediated soil processes. Li et al. (2018) concluded that addition of straw had not only enhanced soil biological perspectives but also altered the soil characteristics which may become suitable for microbial communities. Similarly, Ren et al. (2019) also noted that addition of manures in soil improved 40% SMBC, 55% SMBN, 16% SOC and 21% TN as compared to non-manure doses. Xiao et al. (2018) also suggested that different cropping patterns had improved soil biological health in terms of soil microbial biomass and enzymatic activities. Our results were also in symmetry to their data pertaining to soil microbial biomass C and N.

Mitran et al. (2016) also found that addition of organic matter had developed 51.6 % SMBC, 67.4% fluorescein diacetate, 50% SDH and 62.7% ß-glucosidase activities above control treatment. This variation might be owing to various soil salinity levels in study sites of soil profile. Their findings are also in line with present results that raw material of leguminous crops improved the dehydrogenase activities. Analogously, Hazra et al. (2019) also suggested that wheat-mungbean cropping patterns accumulated more than to maize-wheat cropping patterns. Their findings do exactly match to data presented in Fig. 6 & 7. Interestingly, Borase et al. (2020) also concluded that mungbean based cropping patterns had significantly improved microbial biomass and enzymatic activities. Similarly, Bargali et al. (2019) pointed out that maximum rainfall during the winter season improved the soil microbial biomass and attained optimum SMBC and SMBN levels in tree planted agricultural fields as compared to fallow lands. They concluded that organic matter readiness and fine roots establishment are possible due to better soil quality and optimum soil biomass and enzymatic activities in tree planted plots and vice versa in fallow lands. The present data presented in Figs. 6 & 7 was also in symmetry to their results. Cochran et al. (1989) also concluded that timberland soils had improved soil quality in terms of soil microbial biomass and enzymatic activities as compared to normal fields during warmer climates and vice versa during rainy seasons. The present data for microbial biomass and enzymatic activities was in contradiction to their data.

The soil fertility status under *Triticum aestivum* L. – *Zea mays* L. and *Triticum aestivum* L. *Vigna radiata* L. cropping pattern depicts that soil properties were found basic and calcareous. The soil was also normal due possession of low salts in each cropping outline. The plough layer has adequate to moderate status of TOC, TN and K in each cropping pattern. The plough layer was deficient in available P. The wheat-mungbean cropping patterns had more clay contents in their texture as compared to wheat-maize cropping patterns. Cation exchange capacity is a precursor to indicate the optimum availability of nutrients from soil to plants regarding plant growth and development. On a site specific basis, all seasons behaved regarding soil chemical properties in this way that *Triticum aestivum* L. *Zea mays* L. and *Trtitcum aestivum* L. – *Vigna radiata* L. Overall, wheat-mungbean performed better for restoration of soil nutrient richness parameters than to wheat-fodder cropping pattern. It had been because of maximum nutrient restoration in the plough layer by cover crops like mungbean.

Neha et al. (2020) suggested that greater accumulation of SOC, cation exchange capacity and micronutrients such as Fe, Zn, Mn and Cu had been observed in agricultural farmlands. In addition to this, soil biological characteristics such as soil respiration, SMBC, microbial population, quotients, SDH and SAP activities were also present better in the farmland system as compared to other agricultural land use systems. However, bulk density, available P, available K and metabolic quotients were observed higher under the cropland system. The present results are also in line with their suggestions. The present data depicted that soil fertility status was medium to adequate range under both patterns. Ahmad et al. (2020) found that urban land use systems irrigated by wastewater had significant contributions to P and other soil fertility associated attributes in different times. They observed that across seasons, higher accumulation of organic carbon from soil and water in midstream waste water. Moreover, SMBC, SMBP and available soil P were also present maximum in midstream wastewater and vice versa in canal water command areas. Furthermore, downstream waste water points have accumulated more TP, EC during summer and winter seasons. Hence, their suggestions exactly match our results.

However, organic soils had retained more soil N due to optimum N dynamics and crop yield. It had been possible due to organized soil fertility perspectives to get maximum yield (Doltra et al., 2020). Similarly, Hoffmann et al. (2020) found that more soil organic carbon and nitrogen level in legume fields under sandy soils but resulted in less yield under maize field. Maize monoculture treatments with residues removed reduced SOC moderately by 0.04–0.08 %, while yields declined strongly (> 1000 kg ha^{-1}) as compared to legume field. The present data is also in line with their findings. Mutuku et al. (2020) compared the interrelation among conventional farming and combined soil productiveness management. They concluded that long rainfall distribution improved the soil moisture and soil fertility as compared to short rainfall under the maize field. Nassary et al. (2020) evaluated productivity of maize and bean-based cropping pattern more than five growing seasons. They recommended that induction of legume crops in their existing cropping pattern by replacement of maize may not only improve the soil productivity but also enhance the socio-economic condition of the farming community. These results are in concomitance to their suggestions that inclusion of leguminous crops improve the soil fertility better as compared to maize field. Similarly, Nielsen et al. (2018) found that amended soil reduced 27% yield while un-amended soil had significantly contributed to yield. Admixture of biochar and N fertilizer had increased 30.4-59.6 mg kg^{-1} soil nitrate and maintained 4.59-4.86 soil pH.

Omer et al. (2018) examined soil quality indicators during summer, winter and spring season under different cropping systems. During the summer season, soil physical properties such as aggregate stability, their diameter, available water capacity, and bulk density were predominant. In fall and winter season, SOM and OC were liberated more. In spring season, lower levels of N, P and K were attained. Smith et al. (2016) found that higher accumulation of SOC and N was attained in legume based cropping pattern as compared to conventional crop rotation possessing maize crop. The maize crop had improved the yield only due to maximum N based fertilizer use and high irrigation practice.

Water is essential for biotic life and its availability in soil profile was better and higher during September (18.11%) in wheat-maize cropping pattern. The ASMC was available more during July, August and September as compared to all other months under wheat-mungbean season. This could be attributed to timely rainfall, soil texture, long root proliferation, field embankments, less drainage, optimum organic matter addition and less soil erosion. Pastures and high delta crops are competing for soil moisture for their sustainability and productivity. The ASMC were present less during April, May and June in present study. The present study data (Fig. 8) revealed the same postulates as Wang et al. (2008). Similarly, it was also pointed out by Rockstrom and Valentin (1997) that high delta crop uses maximum soil moisture under arid and sloppy environments. Hence, their suggestions are likewise to our findings. Analogously, Kizito et al. (2007) also concluded and suggested that high delta crops such as millet also utilize more soil moisture in arid environmental conditions. The moisture limited option in arid may become dangerous to disturb the sustainable agro ecosystem in dry lands. However, their findings are also in concomitance to our results. This might be because of timely rainfall distribution, soil texture, long root proliferation, field embankments, less drainage, optimum organic matter addition and less soil erosion. Many other studies also do match to present results pertaining to moisture in plough layer in different cropping patterns at leveled to slope gradient fields (Fu et al., 2000; Gómez-Plaza et al., 2000; Wang et al., 2000; Fu et al., 2003; Gardner & Gerrard, 2003).

Yetbarek and Ojha (2020) studied behavior of moisture flow based on temporal unevenness in cultivated soil profile. It was concluded that during wetting and drying spells, the water level also varied in wheat plots. The temporal variation was dominant at all the depths (72.49-101.46%) that may vary due to moisture and mulching perspectives. The results presented in Fig. 8 also are in line to their suggestion that during summer season, average soil moisture contents depend on rainfall availability and temporal variation. Abera et al. (2020) also worked on the impact of seasonal variation on paddy soils. They noted that early sowing varieties have given low yield and late sowing responded vice versa. It may be because of temporal variation at their growth and developmental stages of each variety. The present results (Fig. 8) were in consistence with their findings. The wheat-mungbean cropping patterns restored more water that in turn would improve the growth of mungbean in all seasons at Kahuta. Ishaq et al. (2020) compared the microbial communities under wheat crop during various growth seasons. In June, the bacterial population was more and less in July but did not differ significantly in various growth seasons. Hence, concluded with the remarks it is not easy to address the microbial activity on small scale sampling. Moreover, the experiments conducted by Lian et al. (2020) also conclude that summer season had a negative impact on soil moisture under vegetation. Their mechanistic suggestions were also similar in trends to present investigations. Similarly, Sahoo et al. (2020) developed interrelation of plough layer wetness and rice cropping under water stressed sites. They suggested that moisture retention was less at downstream sites and upper sites had restored better soil moisture in their profiles. These results (Fig. 8) strongly contradict their finding that soil moisture is present at bottom soil as compared to the upper soil under both cropping patterns.

Yang et al. (2020) observed 11% soil moisture during rainy, 15% during usual and 21% during aridity years by wheat cover crops in spring and autumn season. Hence, moisture restoration in the plough layer was more in April to June under wheat cover crop patterns. They suggested that induction of cover crops not only improve yield but also reduce the evaporation and water drainage through maintaining soil moisture in their micro pores. The present study (Fig. 8) is also in line with their findings that seasonal variations and rainfall distributions have significant impact to wheat-mungbean cropping patterns as compared to wheat-maize cropping patterns. More soil moisture was observed under a restorative cropping pattern (wheat-mungbean) in present study. Analogously, de Queiroz et al. (2020) noted that soil moisture retained better in vegetation crop (0.086 m^3 m^{-3}), inter-mediate in fodder crop (0.064 m^3 m^{-3}) and lower in the deforested area (0.045 m^3 m^{-3}). Finally, they suggested forage and vegetative crops performed better for soil moisture restoration as compared to bare lands. These results are contrary to their findings. In present results, more soil water under wheat-mung bean cropping was noted.

Onwonga et al. (2020) also concluded that significant increases in soil moisture content, organic carbon and carbon stocks and their projections over a 20-year period were evident in maize/dolichos intercrop with farm manure and fertilizer mixture application in both seasons. Their findings are against our results. In our data , wheat-maize cropping systems did not perform better for moisture restoration and wheat-mungbean restored more soil moisture due to owing restorative crops such as mungbean in the study site.

Conclusion

It is concluded from the data that wheat-mungbean (*Triticum aestivum* L. - *Vigna radiata* L. cropping patterns had better soil biological health due to having more SMBC, SMBN, SMBP and SDH and SAP activities as compared to *Triticum aestivum* L. - *Zea mays* cropping patterns under arid environmental conditions. Similarly, the better soil fertility status under *Triticum aestivum* L. - *Vigna radiata* L. The soil moisture varied and remained dependent on rainfall distribution on both cropping patterns**.** The present study findings can become paradoxes for the scientists to verify this fact on broader spectrum, particularly restoration perception in soil agro-ecosystem. It has been suggested that induction of leguminous crops and/or drought tolerant crops can be the best option for farming communities and for soil health in the long run in rain-fed dry farming.

Author Contribution Statement: Rehmat Ullah conducted the experiments of this study. Khaid Saif Ullah Khan planned the research study. Shehzada Munawar Mehdi helped critical reviewing, data analyses and vetting of the paper. Ahmad Nadeem helped for critical reviewing of this manuscript. Fareeha Habib helped for statistical application and Sobia Noor critically reviewed this manuscript.

Conflict of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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