Impact of Cropping Systems on Macronutrient Distribution and Microbial Biomass in Drought Affected Soils.

M. Naga Jayasudha[1], M. Kiranmai Reddy[1,2], Surendra Singh Bargali[3]

1. Department of Environmental Science, School of Sciences, 2. Multi-disciplinary Unit of Research on Translational Initiatives (MURTI), GITAM (Deemed to be University), Visakhapatnam-530045, Andhra Pradesh.

3. Department of Botany, D.S.B. Camus, Kumaun University, Nainital -263001, Uttarakhand, India

Corresponding author: kmajji@gitam.edu

Abstract

The interplay between soil nutrients, water activity, and microbial biomass is pivotal for plant growth as well as for soil health. While surface microflora typically promotes mineralization and nutrient deposits, the impact of drought on soil microbial biomass and nutrient utilization remains underexplored. In this study, we assessed various land types—open lands (OL), annual crops with single species (ACS), perennial crops with multiple species (PCM), less water available lands (LWA), and soil near ponds (CP)—to elucidate the distribution of macronutrients and microbial biomass. Soil samples were collected from different land types, air-dried, and subjected to physical, chemical, and biological analyses. Standardized protocols, including gravimetric and titration analyses, were employed for physical and chemical assessments, while microbial biomass was evaluated using fumigation. Statistical analyses, including ANOVA and Pearson Coefficient, were employed to discern patterns across seasons, soil depths, and microbial biomass. Microbial biomass carbon (Cmic) ranged from 134.2±1.2μg/g to 286.6±1.33μg/g, while nitrogen (Nmic) and phosphorus (Pmic) varied from 11.3±1.3μg/g to 69.5±0.98μg/g and 07.6±1.5μg/g to 77.5±0.6μg/g, respectively, across all seasons. Carbon stock in the upper soil surface positively influenced nitrogen and phosphorus retention. Notably, PCM exhibited superior Cmic, Nmic, Pmic, and water-holding capacity compared to OL, LWA, and ACS. Our findings underscore the significance of multiple cropping systems, particularly PCM, in enhancing microbial biomass and nutrient levels in drought-affected regions. The observed improvements in soil moisture, nitrogen, phosphorous, and potassium levels suggest that diverse cropping systems can effectively enrich soil nutrients and biomass content in drought stress. In conclusion, our study highlights the potential of perennial crops with multiple species in mitigating the impact of drought on soil microbial biomass and macronutrient distribution. These findings contribute to a deeper understanding of sustainable agricultural practices in drought-prone regions and emphasize the importance of implementing diverse cropping systems to enhance soil health and resilience.

Key words: Microbial biomass. Soil properties. Cropping systems. Drought region.

Introduction

One of the important indicators of the soil is microbial biomass, which plays a crucial role in maintaining organic content in the soil by decomposing organic matter and hence controlling the nutrients and maintaining the biogeochemical process of different ecosystems (Wang et al., 2014; Manral et al., 2020). The microbial density and stability are greatly affected by the different ecosystems and the existence of nutrient supplements in the soil (Dietterich et al., 2022; Manral et al., 2023). The present agricultural practices are in high demand for using pesticides, fertilizers, and hybrid seeds at a very high rate, which results in environmental degradation, particularly soil. The productivity of crops mostly depends on the existence of nutrients in the soil that later reflect on the contribution made by the soil microflora in terms of microbial biomass. Amendments of organic contents to the soil provide nutrients that help in the colonization of microbial communities (Bastida et al., 2017), thereby, changes in soil characteristics might be noticed.

Bulk density is directly related to soil compaction. In the open land use system, the bulk density is higher because of the soil compaction (Bargali et al., 1993; Joshi et al., 1997). This is also related to soil microbial activities; due to more soil pore space; moisture supports the microbes to enter the available pore space and enhance their activities and soil becomes more porous in forested land (Bargali K et al., 2018). Vegetation plays a significant role in the formation of soil organic matter (SOM) and influences fundamental soil-forming processes such as aggregation or podzolization (Awasthi et al., 2022 a & b). Han et al., (2021) stated that floristic composition plays an important role in the formation of SOM and influences fundamental soil-forming processes. The texture of the soil may also affect the productivity of the forest by affecting moisture availability and nutrient supply to microbial decomposition (Bargali et al., 2015; Han et al., 2021).

The occurrence of drought might be due to changes in the land use patterns, which change nature by physical, chemical, and biological means, which modifies the soil properties and increases erosion and level of compaction (Geissen et al., 2009; Maranguit et al., 2017). The supply of nutrients in the soil is due to the weathering of rocks and is further processed by the decomposition of the organic matter, which results in different forms as organic and inorganic, available and non-available; however, the carbon, nitrogen, and phosphorus concentration in the soil enriches through microbial activity (Chen et al., 2022). The management of cropping patterns maintains the interaction between soil and microbes by the addition of organic matter either by physical change or by nutrient supply to the soil (Devi & Yadava, 2006). It has been shown that the plantation of mixed tree species has influenced the composition of the aerobic and nitrifying bacterial communities in the soil and has helped mitigate the drought effects in the cropping system (Gillespie et al., 2020). Earlier, it has been demonstrated that soil cropping practices enhance soil's carbon, nitrogen, and phosphorus content and could increase the diversity of soil microbes, enhancing the tolerance to abiotic stresses (Bastida et al., 2017). Therefore, restoring the soil microbial communities, maintaining nutrient cycling, and promoting effective crop productivity is of utmost necessity in drought regions.

Assessing the soil microbial biomass to maintain soil health provides long-term productivity in different cropping patterns. Studies in this line about the different cropping systems and their microbial biomass in drought regions have not been carried out earlier. Furthermore, its relationship with nutrients was also not studied. Hence, an attempt has been made to understand the microbial biomass of carbon, nitrogen, and phosphorus with different cropping systems in the drought region of Andhra Pradesh. Here, a study has been conducted to understand the influences of multiple cropping systems on soil microbial biomass in drought-hit regions in terms of soil depths, seasonal variation, nutrient composition, and diversity. Our findings suggested that multiple cropping systems have helped enhance the soil microbial biomass and macronutrients like carbon, nitrogen, and phosphorous in drought-hit soils.

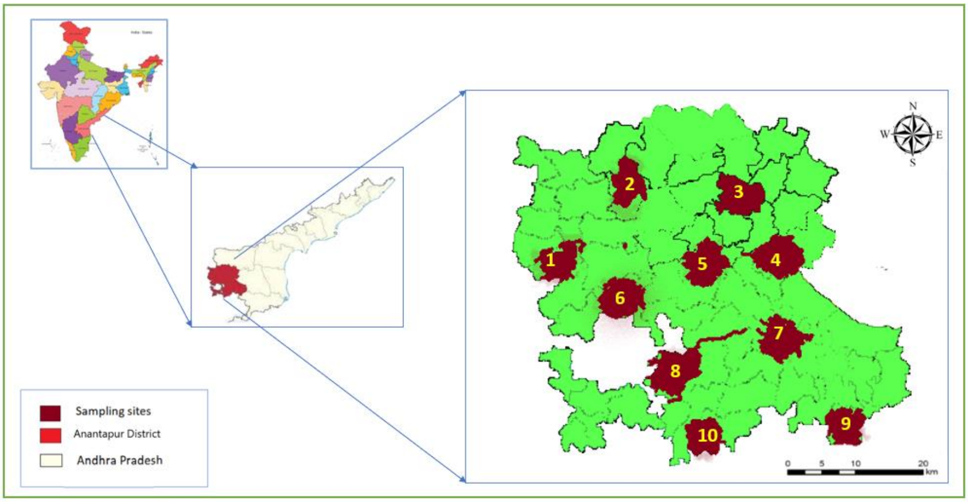

Fig-1 Selected ten sampling sites for the soil analysis of the Ananthapuram district of Andhra Pradesh, India.

2 Material and Methods

2.1 Study area and Climatic conditions

The present study was in the drought-hit region of Anantapur district of Andhra Pradesh with a 14.67° and 14. 80° N, 77.63°, and 78.16°E with an average elevation of 335 m. In the study, the cropping pattern has been categorized as open lands (OL), Annual Crops with single species (ACS), Perennial crops with multiple species (PCM), Less water available lands (LWA), and Crops grown near the ponds (CP) has been selected as control. The pattern of the cropping system has been described in Table 1. The average climatic conditions of the area are semi-arid, with hot and dry conditions and occasional rainfall. The whole is comprised of three seasons, summer with an average temperature of 36° C (March to June), Monsoon (July to October) with a temperature of 31° C, and winter season lasts for three months (November to February) with an average temperature of 18° C.

2.2 Collection of Soil Samples

From the study site, ten samples from 10 different regions were collected randomly from three different seasons, viz., summer, monsoon, and winter, with different soil depths such as upper surface (0-15 cm), subsurface (15-30 cm) and deeper layers (30-45 cm), after collecting soil samples in Ziplock bags, they were transported to the laboratory and air dried. The samples were made into three sub-samples, and different soil characteristics were analyzed.

2.3 Soil Analysis

The physical parameters such as bulk density (BD), soil moisture (SM), water holding capacity (WHC), soil texture, and soil temperature (ST) were analysed (Misra 1968). The texture was analysed with different measurements of the sieve size. The soil's chemical properties are pH, electric conductivity (EC), total organic carbon (Walkley and Black 1934), soil organic matter, total nitrogen (Peach & Tracy 1956), phosphorus (Olsen et al., 1954), and potassium (Pratt 1965). Soil microbial analysis was estimated by taking the surface soils as the activity of microbes will be higher in the surface soils. The chloroform fumigation method is used to evaluate C_{mic}, N_{mic}, and P_{mic} (Brookes et al., 1985; Vance et al., 1987).

2.4 Statistical Analysis

The statistical analysis was carried out by using ANOVA to understand the impact of seasons on the different agrosystems and their interactions with soil nutrients particularly, C_{mic}, N_{mic}, P_{mic}. Pearson's correlation matrix was established for the data collected using SPSS version 16.

3 Results

3.1 Physicochemical characteristics

The information about the physicochemical characteristics of the soil has been tabulated in Table-2 and Table-3. The agricultural systems have a similar texture, indicating that the soil has been derived from the same parental rock, which underwent several physical, chemical, and biological weathering; moreover, due to different management practices, its original characteristics could be changed. The highest sand percentage has been observed in LWA, silt in CP, and clay in PCM. When we look at bulk density, it was seen higher in OL with 2.01 g/cm^3 when compared to CP with 1.65 g/cm^3, indicating that it is more than 10% higher in open lands due to cropping systems. A significant variation has been observed in the WHC parameter, where PCM was identified at 51.2% with the highest and CP with the lowest at 33.24%. The soil temperature ranged from 29.3°C (LWA) to 32.1°C (OL), whereas the soil moisture recorded from 4.08% to 9.43% in all agricultural cropping systems.

The pH is an important chemical characteristic of soil that decides the soil acidity or alkalinity for crop production. It is identified in ACS as 8.93, and others with a range of 7.79 to 8.66. The increase in the pH clearly states the enhanced use of synthetic fertilizers and pesticides in the soil. The dissipation of ions in the soil is also confirmed by the EC study of the different ranges of the cropping pattern, which are in the series of 0.13dS/m in ACS to 0.38dS/m in OL. The variation influences the distribution of ions in the soil. The other chemical parameter in the study which promotes good crop productivity is organic carbon, which rangesfrom 0.24% (LWA) to 0.91% (OL), mostly found in the surface soils compared to subsurface soils.

The soil nitrogen has also shown similar with surface soils having higher concentrations with a range of 1216 kg/ha (LWA) to 1354 kg/ha (OL); in the case of phosphorus 10 kg/ha was observed in LWA whereas 21 kg/ha has been identified in PCM. The potassium levels ranged from 132 kg/ha (LWA) to 432 kg/ha (PCM). The variation in the NPK availability was higher than less water available lands, which are mostly considered discarded lands. Most of these cultivated lands have shown nitrogen with 90% and above compared to low water level lands due to the continuous addition of synthetic fertilizers. The difference might be due to the external addition of fertilizers reducing the loss of nitrogen in the cultivated lands.

3.2 Carbon (C_{mic}), Nitrogen (N_{mic}), Phosphorus (P_{mic}) microbial biomass

In the study, the microbial biomass of carbon-nitrogen and phosphorus has shown higher values for perennial crops with multiple species when compared to other crop soils (Table-4). Throughout the cropping systems, the microbial biomass carbon registered with a range of

177.6±0.89 in OL to 286.6±1.33 in PCM. In the case of $N_{mic,}$ the concentration has ranged from 43.5±0.77 (LWA) to 69.5±0.98 (PCM), whereas the P_{mic} has shown a variation of about 08.7±0.67 in the dry season of CP to a maximum of 77.5±0.6 in the monsoon season of PCM. This clearly indicates the accumulation of organic carbon in perennial crops compared to other cropping systems. The microbial biomass has shown change (Table-5) due to different cropping patterns and seasonal variations. The microbial biomass variation in the soil might be due to the patterns of crops and their interactions with soil, and the exchange of the materials could cause fluctuations in the biomass content. When compared to the C_{mic}, both $N_{mic}$and P_{mic}have shown more concentration, probably due to the interaction of microorganisms to nitrogen and phosphorus being quite quick than carbon, as these are basic requirements for the microbes for the growth stages. In these cropping systems, perennial cropping soils have better physicochemical and biological parameters due to the constituent of the soil, well root structure, and plant litter throughout the year, making the availability of microbial biomass carbon, nitrogen, and phosphorus. Whereas the lowest C_{mic}, N_{mic}, and P_{mic}were found in OL followed by CP due to fewer crops left in these soils, the concentration of C:N and C:P ranged from 11.5±1.9 to 17.2±1.8 and 12.6±1.1 to 22.1±1.4 as marked in Table-4.

3.3 Physicochemical characteristics and their relationship with microbial biomass

Pearson’s correlation between microbial biomass and physicochemical characteristics is given in Table-6. The microbial biomass carbon showed a significant positive correlation with N_{mic} (r=0.69) and P_{mic} (0.234), pH (r=0.55), Organic Carbon (r=0.743), WHC (r=0.789), SM (r=0.665), N(r=0.489), P (r=0.599), K (r=0.564) and have a negative correlation with sand contents. In the case of $N_{mic, a}$ positive correlation has been noticed with P_{mic} (r=0.576), pH (0.63), Organic carbon (0.853), WHC (r=0.493), BD(2.55), SM (0.665), N(r=0.756), P(r=0.486), K(r=0.564), whereas P_{mic} also showed a significant positive correlation with these physicochemical parameters and negative with sand contents as shown in table-6.

4 Discussion

Soil ecology, nutrients richness, and other physical, chemical, and biological properties determine the agriculture sustainability and cropping patterns (Paudel & Sah 2003; Manral et al., 2020) as well as biological responses to biotic and abiotic factors (Bargali et al., 2019; Bisht et al., 2022). A rapid change in climatic conditions, even at short distances, results in pronounced heterogeneity in soil types and their chemical and physical properties (Bargali et al., 2018). The effect of drought conditions on the architecture and ecology of different soils largely depends upon the soil composition, and therefore, the impact of drought on the soil architecture, and biotic and abiotic composition needs to be understood in the different climatic regions. Here, we have brought forth some findings on the different cropping systems on various parameters of the soil in a drought hit region in India to suggest that multiple cropping systems could help in retaining and /or recovering the vigour of the soil.

The quantifiable measures of physical parameters act as soil health indicators that confirm soil fertility. One of the main properties of the soil is its texture, which decides the feasibility of the production of crops. The increase in the percentage of clay in drought–hit soils enhances the chances of retention of water and nutrients, which seems to favour crop productivity. The proportion of sand in LWA land is higher than silt and clay compared to other lands with different crops; this might be due to the addition of sand due to lack or lesser plantations, which replaces the silt with sand through soil erosion phenomenon (Bargali et al., 2018). This brings out that fewer crops in a region show the signs of high sand, and less clay soils further decrease the existence of nutrients. The soil's water holding capacity determines the water retention in the soils to nurture productivity; the PCM lands have high water retention compared to other lands; due to multiple cropping, the retention ability has increased, which correlated with Kirkegaard et al., (2014) findings. Moreover, due to irrigation facilities for an extended period of time resulted in surface water retention (Zhang et al., 2019) compared to LWA. The PCM systems with different cropping seem to modify the soil texture by their litterfall, and the action of microbes probably makes the soils retain water. Cultivated land has shown higher bulk density than uncultivated land, as continuous cultivation results in the compaction of the soil layers compared to fallowed land (Markewitz et al., 2002; Bizuhoraho et al., 2018). Rotation of crops decreases bulk density and increases soil sustainability (Ouda et al., 2018), but in our study, CP has shown lower bulk density compared to PCM systems and ACS systems, possibly due to the presence of water close to these crops, which have moistened the subsurface soils due to drainage. High soil temperature and less moisture content in OL indicate that the lack of plants exposed the soil to an increase in temperature and loosened its moisture content.

The pH of the soil in the cultivated lands was higher than that of the uncultivated land, which might be due to the addition of fertilizer interacting with hydrogen ions. During nutrient intake, plants release H^+ ions, which, in turn, absorb nutrients (Bhatla et al., 2018). In the case of PCM systems, soil pH is low in the surface layers of 0-15 cm, which may be due to the addition of nitrogen fertilizers in which the ammonium gets converted to nitrate through nitrification, resulting in the release of H^+ ions. The nitrates that got released might combine with cations like calcium and magnesium, which are likely to leach to the subsurface, leaving surface soils with low pH, as our studies have correlated to Gikonyo et al. 2022.The values of pH differ from topsoil to subsurface soils; soil carbon and soil nitrogen are negatively correlated to pH, so lower pH exhibits more accumulation of organic matter. Most plants grow well when soil contains mineral acids; and if the soil pH is in the range of 6.0 to 7.0 most bacteria act on the organic matter and release mineral acids. Apart from organic matter pH also determines the usability of phosphorus, if soil is too acidic then addition of phosphorus reacts with iron or aluminum instead of intake to plants, and if soils are too alkaline, then it reacts with calcium and becomes unavailable to soil (Rosen 2014). The electric conductivity of the soil maintains the exchange of cations between crops and the soil. The cultivated land shows higher soil electrical conductivity than uncultivated lands, as adding fertilizers enhances EC; our findings correlated to Adingo et al. (2021). The soil electrical conductivity is positively correlated (0.033) with nitrogen and (0.065) with phosphorus, but negative correlations were shown with potassium (-0.054). The OL systems have shown higher EC compared to other cropping systems, probably due to high evaporation and transpiration from the plants, which might led to the deposition of salts at the root zone. The total organic carbon (TOC) showed a significant difference between different agriculture cropping systems, and it has ranged in a manner of OL>PCM>CP>ACS>LWA from 0.24% (LWA) to 0.9% (OL); this might be due to open lands were not disturbed for many years, resulting into the natural persistence of TOC compared to other lands (Batjes 2014). Like TOC, soil organic matter (SOM) plays an important role in maintaining nutrients; the concentration varies from 0.03% (LWA) to 1.01% (OL). SOM improves the soil functions of storing and supplying macro and micronutrients and finds one of the indicators to determine the productivity and management of different cropping patterns (Sharma et al. 2020). SOM promotes the soil to handle acidity and helps mineral decomposition in the soil; furthermore, the soil ventilation and decomposition of SOM results in lower carbon content (Srivastava & Singh 1989). In the present study, the carbon content is 84% in all the crop-cultivated lands compared to open lands. Less loss of nitrogen has been identified due to continuous cultivation other than nitrogen, which has shown above 90% of its availability in all cultivated lands compared to uncultivated land. Due to the continuous supply of fertilizers to the soil, it retains the presence of nitrogen; similarly, phosphorus also indicated 85% of its concentration in cultivated land compared to uncultivated one.

The variation in microbial biomass is also shown to be significantly different in different cropping patterns. The change in the soil environmental patterns might alter the microbial biomass either on the surface or inner layers of the soil (Wang et al., 2018). Microbial biomass maintains the chemical cycling and physical properties, as it is considered as sensitive indicator that favours organic and mineral fertilization. A study by Rice et al. 1997, that microbial biomass is homeostatic under optimum conditions. If soil lacks nitrogen, carbon or phosphorus then the limitation of microbial biomass might be noticed, and excess leads to over saturation of microbes. So, soil microbial biomass is considered to be a sensitive indicator. Throughout the agricultural cropping systems, C_{mic} has in a series of 134.2±1.2 µg/g to286.6±1.33µg/g for all seasons, N_{mic} recorded 11.3±1.3 µg/g to69.5±0.98µg/g and P_{mic} has in the range of 07.6±1.5 µg/g to 77.5±0.6µg/g in three seasons. The results clearly indicate that the accumulation of debris from plants and perennial roots favours the microbes to deposit biomass, enhancing the soil's C, N, and P (Latati et al., 2017; Kirkegaard et al., 2017). There has been a positive relationship ($p<0.001$) between C_{mic} and soil carbon, which indicates that the richness of organic matter enhances microbial biomass with higher levels (Bargali et al., 2019). PCM has a diverged litter to the soil, and rotation of crops with multiple crops might enhance the release of organic carbon to the soil; thereby, increased C_{mic} would have been noticed. The PCM systems enhance the clay percentage (Table-2), which seems to be favourable for the microbes to retain longer periods due to the retention of water and organic carbon, which enriches the C_{mic}. Further, N_{mic} has shown higher accumulation where there has been a close connection with soil carbon, as nitrogen is available in organic form in the soil where heterotrophic bacteria require carbon as a source of energy. Due to the presence of leguminous crops in PCM systems, the prevalence of nitrogen-fixing bacteria does survive in the vicinity of the root zone (Xing et al., 2022), which likely stimulates the N_{mic} in the soils. Similarly, P_{mic} also has a positive correlation with C_{mic} and plays an important role in microbial function and activity (Zhang et al., 2019; Wang et al., 2022; Manral et al., 2023). Compared to ACS, CP, LWA, OL, PCM systems have crop rotation and deposition of different crop residues in the soil, which supplies organic phosphorus to the soil and gives an impression that encourages the Gram positive bacteria to convert them into P_{mic}. The cropping systems of PCM have a convincing impact on microbial biomass compared to other systems due to good soil properties and litter diversity. Different litters of multiple crops might invade different microbes, which releases nutrients to the soil in a better way, further resulting in enhanced biomass (McDaniel et al., 2014; Padalia et al., 2022).

Different cropping systems produce various residues and root exudates, which boost microbial activity and diversity of the soil. Further, increases soil microbial biomass and establishes C and N cycling (Li et al. 2019). Thus, the PCM systems with different leguminous and non-leguminous plants have shown better soil microbial biomass when compared to other cropping systems of the study.

Microbial biomass richness mostly depends on the soil carbon instead of nitrogen, though the nitrogen might be influenced by the C:N ratio; similarly, the presence of phosphorus also has an influence on biomass carbon with the C:P ratio. The maintenance of the ratio between C: N: P may be due to the litter of multiple cropping, which correlates with the findings of Xu et al. (2013). The C_{mic}/C, N/N_{mic}, and P/P_{mic} percent ratios were in the range of 1.21±0.87 to 1.64±0.76, 0.89±0.89 to 3.89±1.4, 0.98±1.4 to 2.99±0.9 respectively. Our study report fell into the 1.2 to 2.7% range per Devi & Yadava et al. (2006). A study by Ravindran & Yang (2015) found that the ratio of Cmic/C, N/Nmic, and P/Pmic percent was in the range of 1.2 to 3.1% in the forest soils, which is similar to ours. The PCM systems in the study have significantly maintained the abiotic characteristics of the soil, which further improved the plant growth in drought-hit soils.

5 Conclusion

The continuous cultivation deprives the soil of its inherent pool of nutrients, and slowly, the soil becomes unhealthy. To improve the physicochemical and biological characteristics of the soil needed for better crop productivity, multiple cropping and crop rotation with other agriculture practices are suggested. In the present study, we employed these practices in the drought-hit soil of a different regions in the Anantapur district of AP, India. We demonstrated that the proper root system and perennial crops play a key role in enriching the microbial biomass through their diverse litter that invades different microbes. These changes in the microbial community seem to have affected carbon, nitrogen, and phosphorus levels. Moreover, the increase in the concentration of soil organic matter has enriched the diversity of the plants to be grown in the drought regions, making a feasible environment to activate the microbial diversity with different plant communities. Plants growing in these soils would uptake nutrients and release H+ ions, making soil pH acidic and enhancement in WHC, SM, and ST most suitable for sustainable crop productivity. However, further studies would be required for the detailed characterization of microbial diversity in different types of systems used in the present study. and how do they change in response to multiple cropping systems under PCM. The available results clearly suggest that the perennial crop selection in the drought-hit region has significantly improved the total organic carbon, nitrogen, and phosphorus sources in the soil, further improving the interaction of microbes and thereby maintaining the microbial biomass of the soil.

Conflict of Interest: There is no conflict of Interest.

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Authors contribution

The author’s contribution is conceptualization by MKR, NJS, investigation by NJS methodology by MKR and NJS, data curation by MKR & NJS, initial writing by NJS, Writing – writing and editing MKR, NJS, SSB. All authors discussed, reviewed, and agreed to the publication.

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Table:1 Cropping System in Drought Region

Pattern of Crops	Crop species	Pot Herbs
Open Land (OL)	Mangifera indica, Solanum lycopersicum, Citrus sinensis, Ricinus communis, Citrus linetta	Chrysanthemum indicum, Rosa rubiginosa, Justicia infundibuliformis
Annual Crop with single species (ACS)	Zea mays, Sorghum, Oryza sativa, Solanum melongena, Pennisetum glaucum	Tagetes erecta, Chrysanthemum indicum, Coriandrum sativum,
Perennial crops with multiple species (PCM)	Cajanus cajan, Musa acuminata, Murrayakoenigii, Citrullus lanatus	Jasminum sambac, Chrysanthemum indicum, Spinacia oleracea
Less water available lands (LWA)	Arachis hypogaea, Sorghum, Capsicum frutescens, Trigonella foenum-graecum, Helianthus annuus	Trigonella foenum-graecum, Amaranthus caudatus,
Crops are grown near the ponds (CP)	Justicia infundibuliformis, Tagetes erecta, Psidium guajava, Portulaca oleracea, Gossypium hirsulum, Citrus limetta	Justicia infundibuliformis, Tagetes erecta, Portulaca oleracea

Table: 2 Soil Physical properties of different agricultural cropping systems

		Agricultural Cropping systems				
Parameters	Depth (cm)	OL	ACS	PCM	LWA	CP
Sand (%)	0-15	43.12±3.33	42.66±2.98	36.22±2.89	44.25±3.09	43.24±2.59
	15-30	42.22±3.37	40.16±2.81	34.55±2.08	43.55±3.04	42.19±2.53
	30-45	39.67±2.77	38.66±2.70	35.43±2.83	42.92±2.57	41.91±3.29

Silt (%)	0-15	34.12±2.04	27.22±2.17	28.99±1.73	36.24±2.89	37.32±2.72
	15-30	32.12±2.24	30.56±2.13	31.28±1.56	37.12±2.59	38.87±2.33
	30-45	35.22±2.11	29.98±1.79	30.98±2.16	36.88±2.58	37.88±2.65
Clay (%)	0-15	22.76±1.82	30.12±1.50	34.79±2.43	19.51±1.56	19.44±1.36
	15-30	25.66±1.53	29.32±1.75	34.17±2.73	19.33±1.35	18.94±1.13
	30-45	25.11±1.25	31.36±2.50	33.59±2.35	20.2±1.24	20.21±1.61
BD (g/cm^3)	0-15	2.01±0.12	1.93±0.15	1.89±0.09	1.77±0.14	1.65±0.13
	15-30	2.32±0.16	1.98±0.13	1.99±0.15	1.85±0.11	1.72±0.10
	30-45	3.01±0.24	2.01±0.16	2.10±0.16	1.90±0.13	1.89±0.13
WHC (%)	0-15	35.66±2.13	44.56±3.11	51.26±4.10	39.76±2.38	33.24±2.32
	15-30	33.72±2.69	43.23±3.02	49.37±3.94	37.12±2.59	31.98±2.55
	30-45	34.51±2.41	40.12±2.80	47.23±3.34	35.65±2.49	29.67±1.48
SM (%)	0-15	4.08±0.28	6.92±0.48	9.43±0.66	5.32±0.37	5.99±0.35
	15-30	3.98±0.35	4.94±0.39	7.13±0.57	4.15±0.24	4.27±0.29
	30-45	2.89±2.02	3.12±0.15	3.42±0.26	3.23±0.20	2.87±0.17
ST	0-15	32.1±2.56	30.2±1.81	31.2±0.66	29.3±1.46	30.1±2.40
	15-30	26.1±1.82	24.1±1.45	25.6±0.76	26.1±1.82	29.3±2.05
	30-45	25.2±1.76	23.4±1.63	24.3±0.12	25.7±1.79	26.1±1.30
Texture		Loam soil	Loam soil	Loam soil	Loam soil	Loam soil

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Table: 3 Soil Physical properties of different agricultural cropping systems

		Agricultural Cropping systems					
Parameter	Depth	Seasons	OL	ACS	PCM	LWA	CP
pH	0-15	M	8.62±0.63	8.93±0.43	7.79±0.38	8.22±0.49	8.66±0.43
		W	8.0±0.4	7.99±0.47	8.12±0.48	7.8±0.44	7.98±0.47
		S	7.12±0.46	7.72±0.38	7.39±0.44	7.6±0.53	7.35±0.580
	15-30	M	8.92±0.53	8.84±0.53	7.88±0.55	8.45±0.76	8.66±0.43
		W	7.98±0.55	7.8±0.46	8.0±0.48	7.77±0.64	7.7±0.381
		S	7.3±0.58	7.5±0.37	7.2±0.58	7.4±0.44	7.12±0.36
	30-45	M	8.4±0.50	8.6±0.52	7.7±0.54	8.4±0.58	8.2±0.41
		W	7.7±0.53	7.6±0.37	7.9±0.67	7.5±0.45	7.45±038
		S	6.5±0.52	7.2±0.57	7.1±0.49	7.35±0.5	7.2±0.36
EC	0-15	M	0.38±-0.026	0.13±0.061	0.26±0.023	0.29±0.026	0.22±0.01
		W	0.26±0.02	0.11±0.05	0.22±0.0132	0.25±0.02	0.21±0.0105
		S	0.28±0.351	0.12±0.007	0.2±0.016	0.21±0.014	0.11±0.008
	15-30	M	0.28±-0.019	0.12±0.011	0.2±0.018	0.22±0.019	0.14±0.012
		W	0.22±0.01	0.11±0.009	0.13±0.0064	0.20±0.01	0.13±0.009
		S	0.28±0.01	0.10±0.009	0.11±0.0066	0.19±0.013	0.11±0.005
	30-45	M	0.15±-0.01	0.14±0.011	0.16±0.011	0.19±0.015	0.19±0.0114
		W	0.26±0.02	0.13±0.009	0.15±0.0105	0.14±0.009	0.17±0.102
		S	0.28±0.025	0.11±0.007	0.13±0.0091	0.12±0.008	0.14±0.0112
TOC (%)	0-15	M	0.91±0.43	0.45±0.037	0.6±0.04	0.24±0.016	0.6±0.03
		W	0.82±0.35	0.33±0.026	0.49±0.029	0.19±0.0133	0.59±0.029
		S	0.61±0.050	0.24±0.016	0.45±0.040	0.16±0.013	0.52±0.028
	15-30	M	0.77±0.06	0.32±0.027	0.2±0.012	0.19±0.05	0.56±0.026
		W	0.62±0.037	0.29±0.02	0.19±0.013	0.12±0.01	0.3±0.029
		S	0.52±0.036	0.16±0.011	0.09±0.006	0.10±0.009	0.2±0.016
	30-45	M	0.53±0.037	0.21±0.0074	0.1±0.009	0.18±0.014	0.6±0.048
		W	0.31±0.015	0.123±0.010	0.11±0.008	0.14±0.0113	0.59±0.04
		S	0.1±0.009	0.10±0.006	0.08±0.007	0.11±0.008	0.52±0.03
SOM	0-15	M	1.01±0.080	0.22±0.015	0.48±0.043	0.03±0.002	0.48±0.02
		W	0.86±0.077	0.01±0.0009	0.29±0.023	0.02±0.001	0.46±0.032

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	15-30	S	0.499±0.044	0.13±0.01	0.223±0.017	0.01±0.0009	0.37±0.018
		M	0.77±0.061	0.12±0.0088	0.12±0.009	0.10±0.008	0.41±0.032
		W	0.51±0.040	0.21±0.0177	0.11±0.008	0.09±0.0072	0.06±0.004
	30-45	S	0.34±0.020	0.10±0.007	0.06±0.0048	0.07±0.004	0.12±0.0108
		M	0.36±0.028	0.08±0.0072	0.1±0.007	0.19±0.015	0.48±0.023
		W	0.16±0.01	0.01±0.0009	0.09±0.007	0.11±0.005	0.46±0.034
N (kg/ha)	0-15	S	0.07±0.006	0.013±0.00066	0.09±0.006	0.026±0.0023	0.34±0.015
		M	1354±67.7	1323±66.2	1316±65.8	1216±60.8	1322±66.7
		W	1331±66.55	1201±72.06	1177±58.85	1173±70.38	1296±77.85
	15-30	S	1206±72.36	186±9.3	1186±58.85	1156±57.8	1243±87.01
		M	856±42.89	729±36.45	845±59.15	677±33.85	987±49.3
		W	728±36.4	623±37.38	633±31.65	523±26.15	865±43.25
	30-45	S	655±39.3	432±30.23	524±31.44	416±29.12	401±20.05
		M	254±12.7	223±13.38	216±15.12	206±14.42	312±15.6
		W	231±13.86	201±10.05	188±13.16	194±9.77	296±14.8
P (kg/ha)	0-15	S	216±10.64	186±11.16	196±13.72	186±4.72	286±17.16
		M	19±1.14	18±1.08	21±1.68	10±1.2	14±1.3
		W	25±1.5	26±1.82	36±2.88	18±1.08	26±1.3
	15-30	S	32±1.92	44±4.16	57±2.85	27±1.35	38±2.28
		M	17±1.20	14±2.3	17±0.85	5±0.3	10±0.5
		W	18±1.88	20±1.2	31±2.17	8±0.56	19±1.33
	30-45	S	27±1.35	39±2.34	49±2.45	19±0.95	29±2.32
		M	10±0.6	11±0.73	11±0.55	4±0.24	11±0.66
		W	8±0.72	16±0.92	16±0.87	7±0.49	16±0.8
K (kg/ha)	0-15	S	12±0.6	25±1.76	27±1.35	17±1.19	22±1.1
		M	267±13.35	232±11.6	432±21.6	132±9.24	143±8.58
		W	302±15.1	421±21.05	655±32.75	144±11.52	198±9.9
	15-30	S	393±19.65	540±32.4	829±41.45	160±12.8	255±12.75
		M	156±13.32	136±9.52	242±12.1	112±8.96	111±5.55
		W	222±11.1	226±15.82	402±24.2	125±7.5	154±9.24
	30-45	S	304±15.2	430±21.51	666±33.3	103±8.24	178±10.68
		M	107±6.42	102±8.19	367±22.02	107±6.42	98±4.9

		W	150±7.5	143±7.15	398±23.88	121±6.04	122±6.2
		S	265±13.25	339±20.34	523±31.38	90±6.31	165±8.25

Table: 4 Different agricultural cropping systems and their microbial biomass of carbon, nitrogen and phosphorus

Agricultural Cropping system	Seasons	C_{mic} (µg/g)	N_{mic} (µg/g)	P_{mic} (µg/g)	C_{mic}: N_{mic}	C_{mic}: P_{mic}	C_{mic}/C(%)	N_{mic}/N(%)	P_{mic}/P(%)
OL	M	177.6±8.89	47.4±2.65	36.3±0.32	5.4±0.29	3.4±0.27	1.43±0.99	1.76±0.14	1.56±0.12
	W	156.3±7.77	21.2±1.63	18.2±0.98	8.9±0.56	9.7±0.52	1.59±0.12	0.89±0.078	0.98±0.07
	S	134.2±6.2	9.44±1.2	10.9±0.45	13.6±1.08	15.6±1.2	1.31±0.10	1.65±0.14	1.43±0.10
ACS	M	233.1±11.3	56.5±3.4	46.4±1.1	3.4±0.23	4.4±0.35	1.31±0.14	2.55±0.20	2.32±1.3
	W	209.09±10.96	29.3±2.3	26.9±1.4	5.3±0.43	6.4±0.51	1.64±0.15	1.76±0.14	1.56±0.10
	S	198.4±9.77	11.7±1.1	07.6±1.5	14.7±1.14	17.3±1.21	1.43±0.7	1.54±0.13	1.22±0.09
PCM	M	286.6±17.33	69.5±6.25	77.5±0.6	4.5±0.22	6.7±0.47	1.22±0.09	3.89±0.31	2.99±0.20
	W	279.8±20.98	45.67±3,19	55.9±0.3	9.7±0.57	11.6±0.65	1.46±0.13	1.78±0.12	1.47±0.08
	S	240.3±19.2	32.3±1.93	36.7±0.5	17.2±1.37	22.1±1.74	1.64±0.16	2.77±0.19	2.05±0.16
LWA	M	220.7±13.26	43.5±3.07	53.8±1.2	3.2±0.28	4.5±0.44	1.86±0.12	2.12±0.14	2.05±0.18
	W	198.5±9.21	31.9±1.1	30.4±0.5	8.6±0.68	9.7±0.77	1.79±0.10	1.54±0.09	1.41±0.08
	S	176.3±10.65	19.3±1.91	18.2±0.66	14.6±0.79	13.5±1.03	1.45±0.075	1.87±0.09	1.65±0.13
CP	M	198.2±13.76	44.8±3.51	39.8±0.76	5.5±0.44	6.5±0.48	1.32±0.098	2.89±0.20	2.16±0.17
	W	167.3±0.88	26.6±1.33	21.2±1.3	7.1±0.42	8.7±0.52	1.21±0.087	2.03±0.16	1.98±0.11
	S	145.6±15.05	11.3±0.67	08.7±0.67	11.5±0.69	12.6±1.13	1.34±0.12	1.85±0.12	1.45±0.10

Table:5 Pearson's corelation coefficient between agricultural systems, seasons, microbial biomass and physicochemical parameters

	AS	S	C_{mic}	N_{mic}	P_{mic}	pH	EC	TOC	WHC	BD	ST	SM	N	P	K	Sa	Si	Cl
AS	1																	
S	0.001	1																
C_{mic}	0.264	0.233	1															

N_{mic}	0.0887	0.199	0.698**	1														
P_{mic}	0.12	0.21	0.234	0.576**	1													
pH	-0.498*	0.779	0.556	0.63	0.725	1												
EC	-0.2*	-0.23*	0.23	0.22	0.2	0.2	1											
TOC	0.323	0.042	0.743*	0.853**	0.886**	0.032	0.227	1										
WHC	0.033	0.086	0.789*	0.493	0.556	-0.287	0.22	0.567**	1									
BD	-0.723**	0.456	0.191	0.255	0.266	0.568*	0.278	0.346	0.160	1								
ST	-0.002	-0,889**	-0.284	-0.422	-0.456	-0.657*	-0.168	-0.215	-0.115	-0.497*	1							
SM	-0.0034	0.336	0.533*	0.665**	0.834	-0.014	-0.021	0.556*	0.335	0.210	-0.489*	1						
N	0.076	0.215	0.489**	0.756**	0.886	0.066	0.033	0.623	0.365	0.256	-0.561*	-0.571*	1					
P	-0.143	0.038	0.599**	0.486	0.578	0.014	0.065	0.598*	0.443	0.213	-0.433	-0.446	0.487	1				
K	-0.144	0.056	0.651	0.564	0.665	0.025	-0.054	0.532*	0.465	0.223	-0.369	-0.398	0.465	0.478	1			

Sa	0.298	0.000	-0.654**	-0.587**	-0.445	-0.0887	0.022	-0.687**	-0.756**	0.102	0.229	-0.226	-0.229	-0.671	-0.587	1		
Si	0.498*	0.000	-0.140	0.012	0.032	0.199	0.022	0.006	-0.654**	0.109	0.139	-0.127	0.156	0.007	0.001	0.273	1	
Cl	-0.534*	0.000	0.345	0.186	0.266	-0.136	0.014	0.265	0.628**	0.112	0.221	0.207	-0.015	0.267	0.245	-0.564*	-0.875	1

Table:6 Pearson’s correlation of microbial biomass indices.

	C_{mic}	N_{mic}	P_{mic}	C_{mic}:N_{mic}:P_{mic}	C_{mic}/C(%)	N_{mic}/N(%)	P_{mic}/P(%)
C_{mic}	1						
N_{mic}	0.961**	1					
P_{mic}	0.882	0.912**	1				
C_{mic}:N_{mic}:P_{mic}	-0.663**	-0.792**	-0.801**	1			
C_{mic}/C(%)	-0.212	-0.345	-0.226	0.110	1		
N_{mic}/N(%)	0.569**	0.963**	0.843**	-0.679**	-0.269	1	
P_{mic}/P(%)	0.412**	0.864**	0.765**	0.115	-0.439	-0.643**	1