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Utilization of Cover Crops for Proper Agroecosystem Services Delivery in Wheat to Promote Sustainable Agriculture

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Abstract:- Non-marketable crops are increasingly being used as a tool to promote agroecosystem services and sustainable agriculture. Nevertheless, crops vary greatly in the traits by which they capture resources and influence the local ecosystem. Here we report on the traits of wheat crop that relate to aboveground biomass production, nutrient capture, weed suppression and soil building by the influence of 4 different cover crops. All agroecosystem services were positively correlated with maximum crop biomass and leaf area. Root density was positively associated with indices of other soil building attributes; total organic carbon, total nitrogen and aggregate stability. Wheat with faba bean legume cover crop produced the highest standing N and P in aboveground biomass. Similarly, faba bean cover crop diminished the emission greenhouse gases; CO_2 and CH_3 in wheat crop to large extent from soil to atmosphere which is positive aspect in mitigation of climate change. Conversely, wheat with brown mustard cover crop had the highest level of weed suppression, butalso suppressed weed biomass and weed cover. Thus, not all cover crops are equal in their ability to promote all agroecosystem services in wheat, and while some cover crops may be ideal for promoting a specific agroecosystem service, this could result in an exchange with another. Nonetheless, our study demonstrates that plant functional traits of wheat are informative for the selection of cover crops for promoting agroecosystem services.

Keywords:- *Cover crops; greenhouse gases emission; nutrient capture; soil-plant interactions; soil and plant health.*

I. INTRODUCTION

The ability of agroecosystems to sustain other valued services and local biodiversity is jeopardized by unfavorable long-term trade-offs associated with intensive farming techniques intended to increase yields, as has been increasingly apparent over the past few decades (Zhang et al., 2007, Pretty & Bharucha, 2014, Fróna et al., 2019). Important agroecosystem services include ecosystem functions including weed control, the development and maintenance of soil organic matter, and effective nutrient cycling in soils, all of which promote agricultural productivity and sustainability for the benefit of human societies. In order to "leverage natures technologies," it is now necessary to create techniques for the ecological intensification of cropping systems (Power, 2010, Gaba et al., 2015, Newbold et al., 2015, Emmerson et al., 2016).

Full-season cover crops are crops that are rotated in an agroecosystem to maintain, restore, or improve good, but non-marketable, ecological qualities (Philip Robertson et al., 2014). They are more accurately referred to as "agroecological service crops." Cover crops, while often non-marketable, are a versatile agricultural technique used to supply valuable agroecological services that may be absent in an agroecological system. These service crops are frequently chosen for the benefit of increasing the output of a subsequent cash crop in a cyclic sequence (Tilman, 1999, Bender et al., 2016). Agricultural service crops, on the other hand, have the potential to reduce the environmental impact of agricultural operations (Snapp et al., 2005, Blanco-Canqui et al., 2015, Daryanto et al., 2018, Abdalla et al., 2019). As of now, a wide range of plant species with varied properties have been deemed to be viable cover crops. Plant-specific functional features can be used to accomplish a wide range of ecological properties. Legumes, for example, may deliver organic sources of N via N-fixing, potentially displacing a portion of a crop's fertilizer N requirements (Thorup-Kristensen et al., 2003). Brassica family members (e.g., mustards) have been recognized for their ability to reduce soil pathogens (Wittwer et al., 2017), and many crops in this family are employed for combating invasive agricultural weeds (Ordóñez-Fernández et al., 2018). Cover crop treatments have the ability to be adjusted to diverse agricultural production systems and to address specific agroecosystem services because to their wide variety and flexibility. The use of functional features and identities for choosing cover crops designed to target and improve specific ecosystem services has been advocated (Perrone et al., 2020).

Plants have evolved a wide range of characteristics in order to collect resources, fight against predators, and compete with nearby species (Friberg at al., 2009, Sharma et al., 2018). Beyond their taxonomic identity, these plant ‘functional features' can provide explanations for how plants influence and adapt to the local ecology (Teasdale, 1996, Jin et al., 2019). Leaf area, leaf mass per area, maximum canopy height, and rooting traits, in particular, frequently correspond with nutrient capture and concurrence against neighboring species (Teasdale et al., 2007), herbivore defense (Brust et al., 2014), the advancement of desirable soil microbial communities (Lefebvre et al., 2018), and soil erosion control (Tribouillois et al., 2015). As a result, it has been claimed that the application of plant functional features may be useful in forecasting how crops may increase agroecosystem services (Blesh, 2018).

Nevertheless, more empirical research is required because the use of functional crop features to forecast their impact on different agroecosystem services is yet in early stages and does not account for the complete range of prospective cover crops. The study evaluated the impact of 4 cover crops, also known as agricultural service crops, grown in wheat plots to estimatedifferent ecosystem services of wheat. These services include crop biomass production, nutrient uptake (which includes N and P), weed suppression (weed biomass and weed cover), soil building (organic matter, N, carbon and soil aggregate stability, extractable phosphorus and available potassium), and soil health (using a variety of soil fungal and bacterial indices).

II. METHODS

A. *Experimental Design*

To understand and study a wide range of agroecological servicesprovided by wheat under the effect of different cover crops, we picked 4 cover crops from different functional categories along with control (no cover crop); brown mustard from brassicas, faba bean from legumes, sunflower from forbs and oat from grasses (Table 1).All four crops were sown as cover crops after 35 days of wheat germination.The experiment took place at the University Research Farm, PMAS Arid Agriculture University Rawalpindi, Punjab, Pakistan during fall 2022-2023 from 21 October 2022 to 14 March 2023.The crops were planted to the sides of 5 m x 6 m (l x b) plots of wheat as monocultures, and they were in three replications.A total of 15replicate plots including control (no cover crop) were arranged into randomized complete block design (RCBD). The soil properties of the field were employed to ensure the robustness of our findings in comparison to before sowing and after harvesting of crops; P_2O_4 = 169 ppm; K_2O = 45 ppm; NO_3 = 6.2 ppm, organic matter = 1.2%, pH = 6.1. Previously soybean was grown on these plots. Land was prepared by using mold board plough for deep ploughing andthen used simpler cultivator for 2 times with 1 planking at last. After land preparation, seeds were planted with a hand drill with a 1–3-inch depth and a 6-inch row spacing. Based on suggested rates for every crop, seeding rates were determined (Table 1). Urea and DAP was applied as a source of nitrogen and phosphorus at the recommended rates. Both fertilizers were applied at time of sowing.

Table 1: List of cover crops sown alongside wheat with their common names, scientific names, functional categories, varieties and seed rates in kg/ha(rate).

Common Name	Scientific Name	Functional Category	Variety	Seed Rate
Brown mustard	*Brassicajuncea*	Brassica	Nifa gold	8
Faba bean	*Vicia faba*	Legume	Low tannin	150
Sunflower	*Helianthus annus*	Forb	Hysun 17	10
Oat	*Avena sativa*	Grass	Sgd. Oat. 2011	75

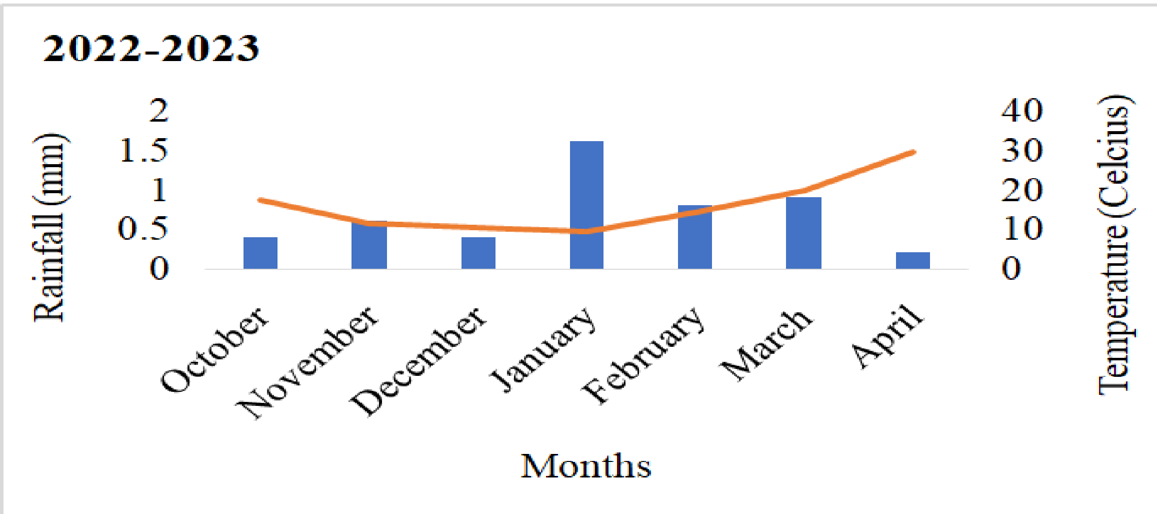


Fig. 1: Average temperature and rainfall in the experimental site (University Research Farm, Rawalpindi) during October 2022 to April 2023. (Source: Climate Observatory at University Research Farm, 350 m away from experimental location)

B. Agroecological Services Estimation

The whole list for the parameters of the different ecosystem services is mentioned in Table 2. We have recorded the green biomass of wheat grown with all the cover cropsunder observation during the experiment season. Biomass was estimated by weighing the plant samples through electrical balance taken from $1m^2$ area of the experiment site with aid of quadrate. The average of three measurements taken along a transect across the center of the plot was used to calculate the canopy height. Leaf area was determined by The Montgomery equation (ME). ME assumes that leaf area (A) is a proportional function of the product of leaf length (L) and width (W), i.e., $A = cLW$, where c is called the Montgomery parameter. Five leaves were sampled from each croptreatme nt in order to determine the leaf area index (LAI).The leafarea index (LAI) was computed by dividing leaf area with the total ground area of plant.

For weed parameters, we have calculatedweed biomass and weed cover. Weed biomass was estimated after pooling and same as we found green biomass of crops.Crop, weed and leaf samples were all dried at 75 Celsius for at least 48 hours. The dried biomass of the crops was ground into a fine 2 mm powder and utilized to determine the percentage P content using the Olsen P method and the percentage N content using the recommended Kjheldal digestion method. Next, the percentage of N or P and the biomass of the standing crop were multiplied to determine the standing N and P of the crop in g/m^2.

Composite soil samples (0–15 cm depth) were obtained from each experimental unit for post-harvest soil analysis of Total Organic Carbon (TOC), aggregate stability, total nitrogen, extractable phosphorus and available potassium. To find out the value of Total Organic Carbon (TOC) we haveappliedWalkley and Black method was followed to determine OC titrimetrically. To find out the value of extractable phosphorus, soil was shaken with 0.03 M NH_4F—0.025 M HCl solution at pH < 7.0. Total nitrogen was determined by Kjeldahl digestion method. To evaluate the value of available K we have used the ammonium bicarbonate-DTPA technique (AB-DTPA).

Using 4.0 g of air-dried soil aggregates with a 1-2 mm size, aggregate stability was assessed by wet screening using an Eijkelkamp wet sieving equipment. Samples were put into a 250 mm sieve, sprayed with a little water, then submerged many times for three minutes.The aggregate particles that made it past the sieve were dried, weighed, and filtered. After being continuously soaked for intervals of five minutes in a 2 g/L NaOH dispersing solution, the particles left on the sieve were reduced to just sand particles. Sand was subtracted from the mass aggregates to determine the percentage of soil aggregate stability (Wendling et al., 2016).

We also took a 7 cm diameter and 15 cm deep soil core around the focal crop in the center of the plant and soil sampling in order to determine root density, or the number of roots per volume of soil. After completely cleaning the roots of dirt, they were dried for at least 48 hours at 65°C. Before being left as green manure for the winter, fields 1 and 2 were flail mowed at 66 and 80 DAP, respectively.

We have determined the carbon dioxide (CO_2) and Methane (CH_3) fluxes from soil into the atmosphere using chamber technique from the experimental area.The chambers were self-constructed with plastic transparent glass and were faced down on the soil surface from where we have taken our readings. The chambers consisted of two thermometers, one inside and one outside the chamber to evaluate the temperature of both conditions. Along with that, two cooling fans were adjusted to the upper side of chambers. The function of the colling system was to regulated the temperature of the chambers. The corners of the chambers were covered with aluminum foils so that air cannot get inside the system. The gas analyzer meters were connected outside the structure through wire to observe the different series of CO_2 and CH_3.

Flux rate (Fgas) was calculated using the following equation:

$$Fgas = Kgas \cdot (273 \cdot Tair^{-1}) \cdot (V \cdot A^{-1}) \cdot (dc \cdot dt^{-1})$$

where:
Fgas – Gas flux density (mg/m2/h)
Kgas – gas-constant at 273.15 K = 0.536 (μg/μl)
Tair – air temperature in chamber (K)
V – chamber volume [l]
A – collar area (m^2)
$dc{\cdot}dt^{-1}$ – Gas concentration change in chamber (ml/l1/h).

Protein content for grain was determined through conversion factor 6.25 into the total nitrogen estimated byKjeldahl digestion apparatus. On the other hand, grain yield was estimated from 1 m^2 area and then multiplied by 10000 to get the value in hectare.

C. Data Analysis

All results were expressed as the means of five biological replicates (n = 5). Statistical analysis was performed using one-way ANOVA in the SPSS 22 ($p \leq 0.05$)(Wendling et al., 2016). Data normality was checked by using Levene's test. Meanwhile, the hierarchical cluster analysis Euclidean distance was performed by using the R stat software package (version 4.5.0, the R)(Saleem et al., 2020).

III. RESULTS

A. Aboveground Traits

The most effective cover crops to optimize the aboveground crop biomass of all the sown wheat during winter 2022-23were brown mustard, faba bean, oat and sunflower (Figure 2a). Wheat grown under brown mustardcover crop had the largest leaf areafollowed by faba beanand sunflower (Figure 2b). The highest leaf area index (LAI) was maximized by brown mustardcover crop followed by faba beanwhile minimum LAI in wheat was recorded for control where no cover crop was sown (Figure 2c).

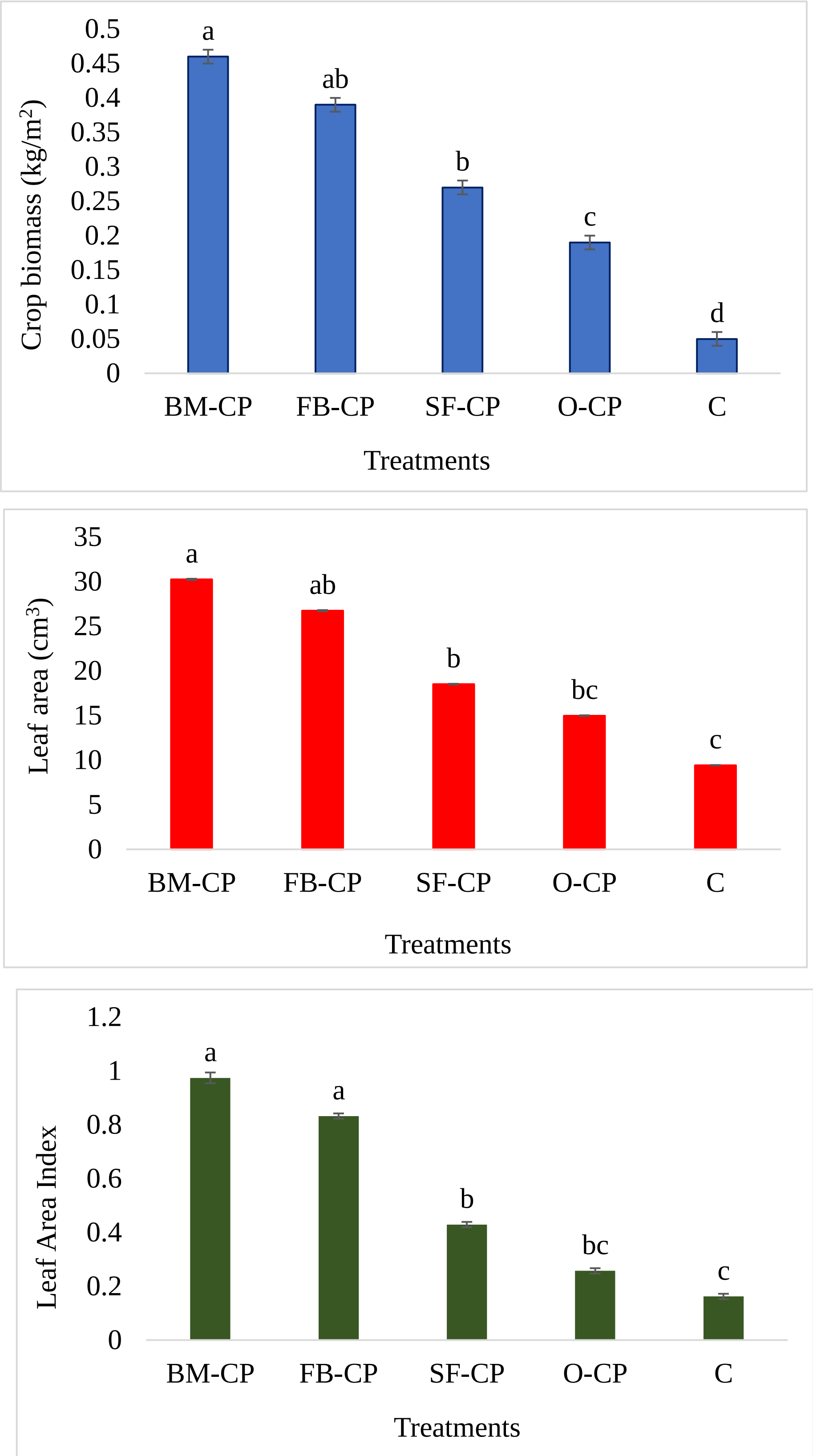
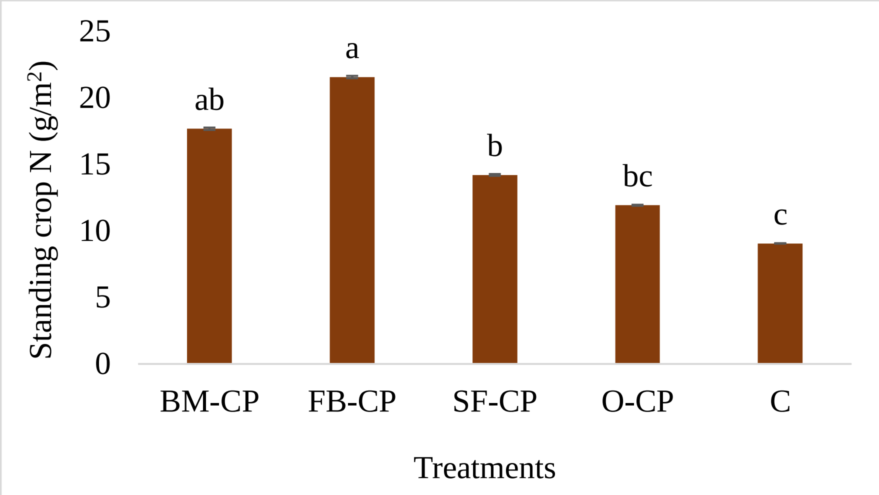


Fig. 2(a, b & c): Crop biomass (a), leaf area (b) and leaf area index (c). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

B. Nutrient Capture

The faba beancover cropping had experienced the highest standing N content in wheat, followed by brown mustardwhile least was observed by no cover crop zone and oat cover crop (Figure 3a). Similarly, wheat with faba bean cover cropping had the highest standing P, followed bybrown mustardand sunflower (Figure 3b). At the conclusion of the growing season, the content of ammonium (NH_4) in the soil varied little between crops, although it was highest withfaba bean and brown mustard as a cover crop and minimum where there was no covercropping(Figure 3c).



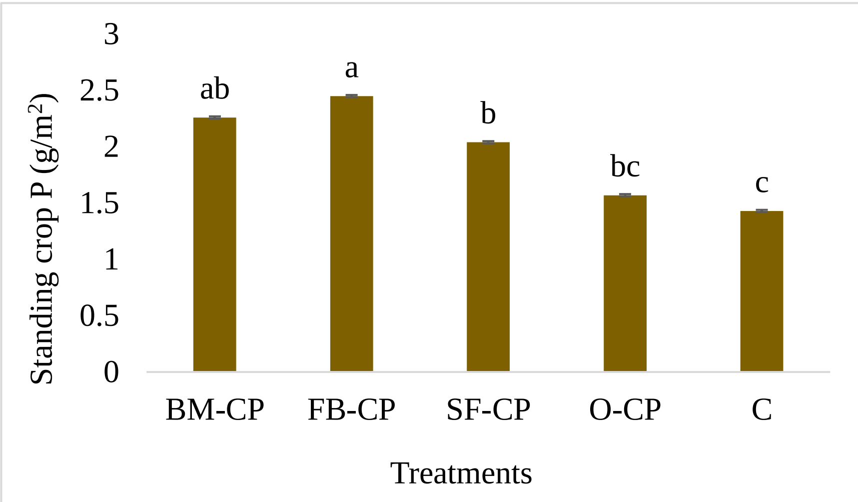
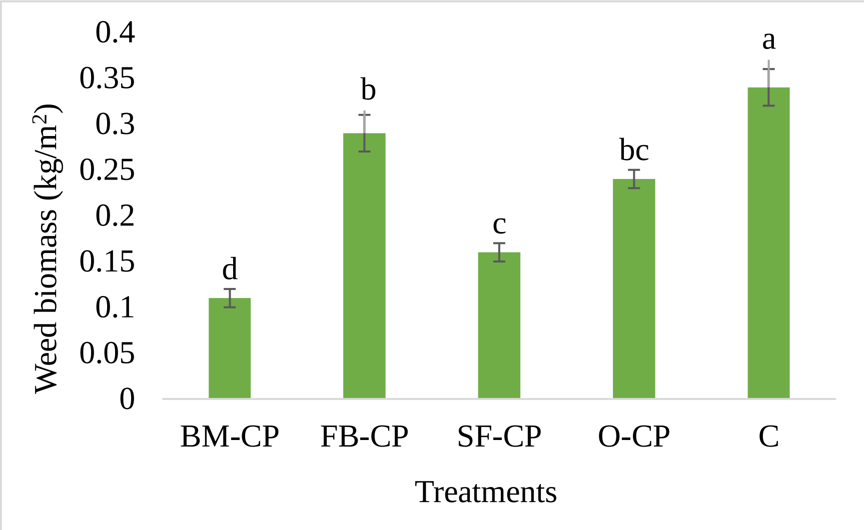
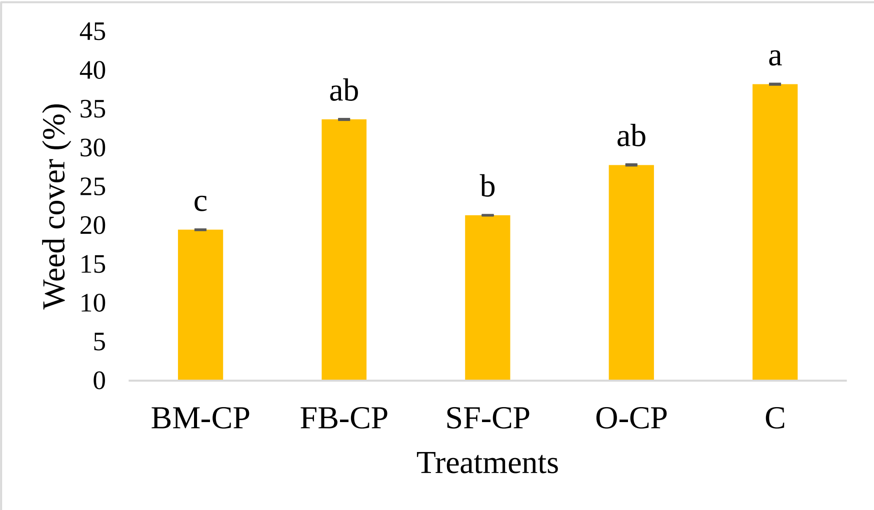


Fig. 3(a & b): Standing crop N (a) and Standing crop P (b). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

C. Weed Suppression Traits

Wheat grown with no cover crop produced the most weed biomass and weed coverfollowed by wheat with faba bean cover crop (Figure 4a, b), whereas brown mustardcover crop has diminished the weed biomass and cover in wheat. As a result, weed suppression—which is the opposite of weed biomass and cover—also differed greatly between these cover crops. The brown mustard, sunflower followed byoatshowed the highest suppression while the lowest weed suppression was observed with no cover crop and faba bean cover cropin wheat(Figure 4c).





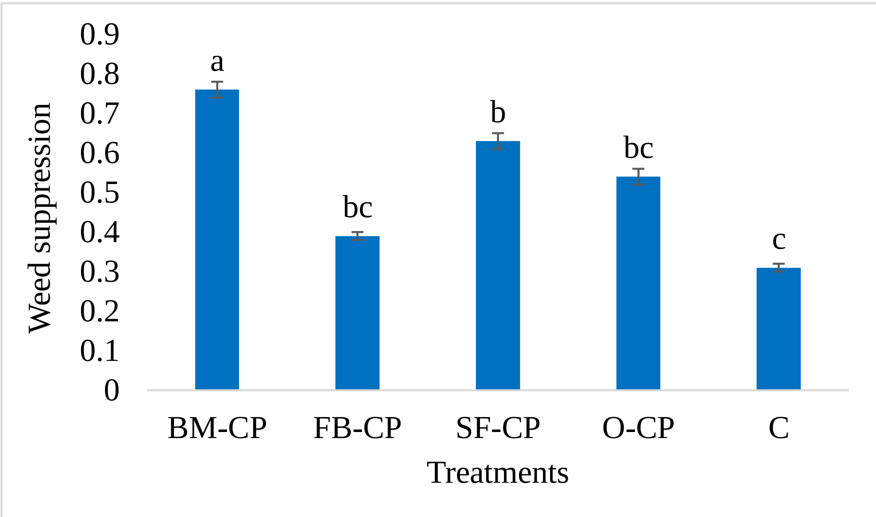
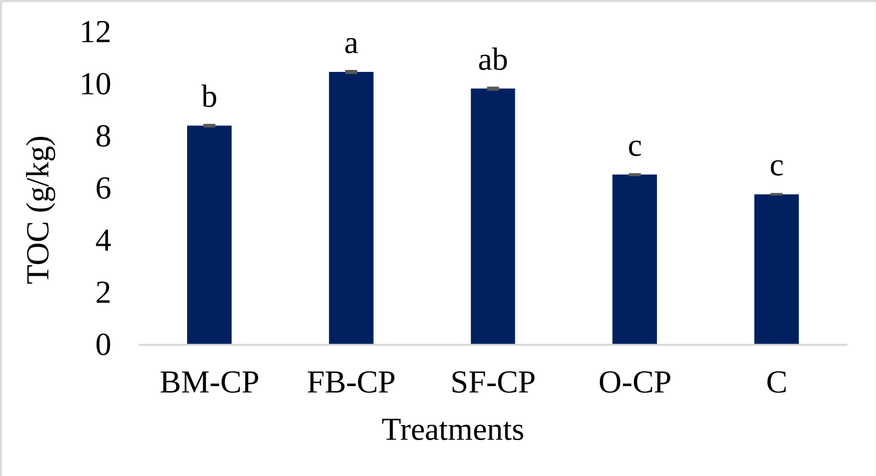


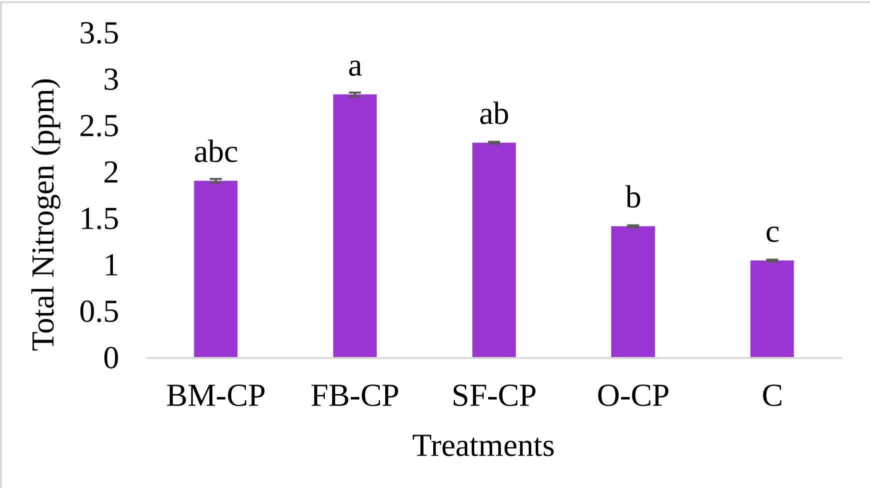
Fig. 4(a &b & c): Weed biomass (a), weed cover (b) and weed suppression (c). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

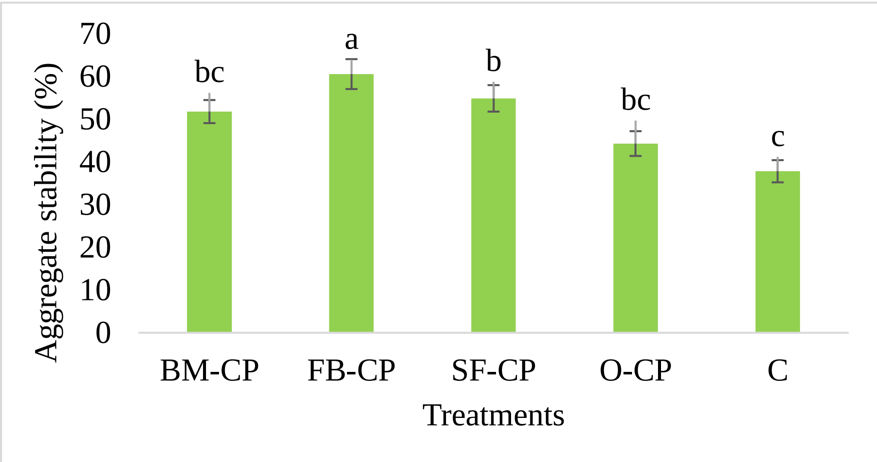
D. Soil Building Traits

There was no discernible difference in the total organic carbon and total nitrogen content of the soil across cover crop application especially in faba bean and sunflower(Figure 5a, b). Cover crops did differ considerably in terms of aggregate stability; wheat with faba bean cover crophad the greatest aggregate stability followed by sunflower, while wheat with no cover crop followed by oathad the lowest value of aggregate stability (Figure 5c).

The root density of wheat has observed significant changes in the presence of cover crops. The root density was increased with faba bean cover crop followed by brown mustard. On the other hand, the negative increase was estimated in root density of wheat where no cover crop was grown followed by oat (Figure 5d)







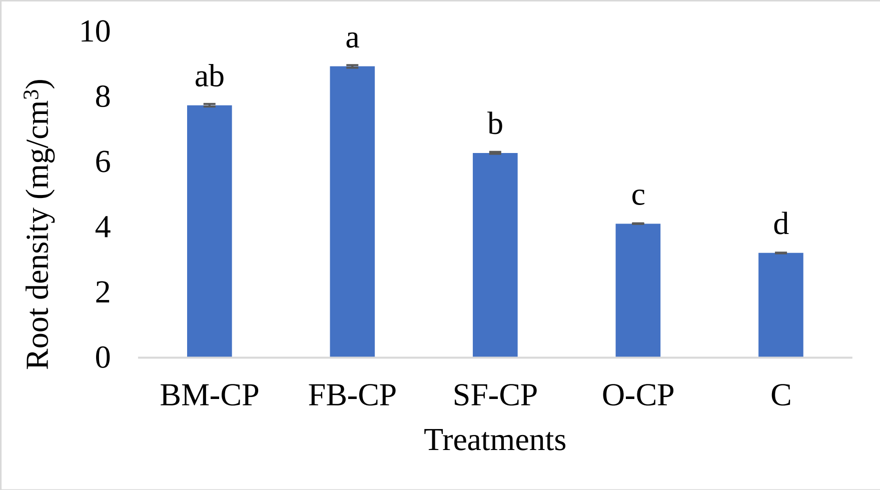
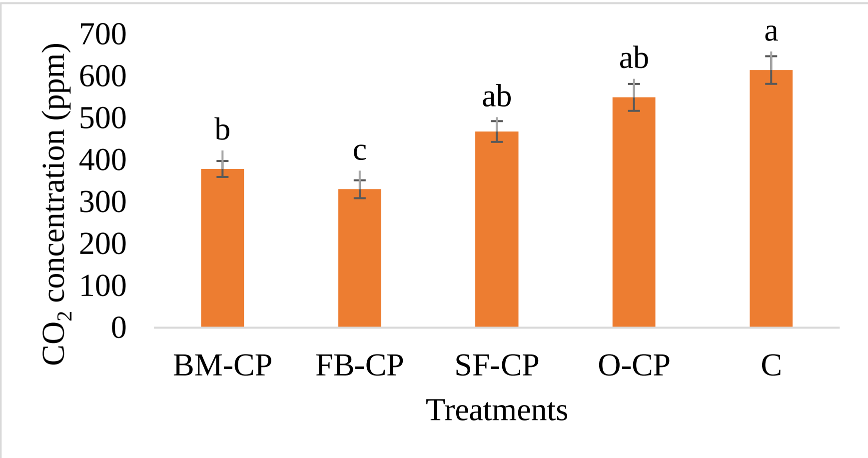


Fig. 5(a, b, c & d): Total organic carbon (TOC) (a), total nitrogen (b), aggregate stability (c) and root density (d). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

E. Greenhouse gas (GHG)Emission

The emission of gases like CO_2 and CH_3, from soil to atmosphere is always considered as threat to our ecosystem. Growing of cover crops in wheat plots positively influence these fluxes. Faba bean legume followed by brown mustard cover crop has observed considerably low amount of emission of CO_2 and CH_3 into the atmosphere in wheat grown plots. Alternatively, there is increase amount of carbon dioxide and methane emission in wheat with control (no cover crop) and oat cover crop (Figure 6a, b).



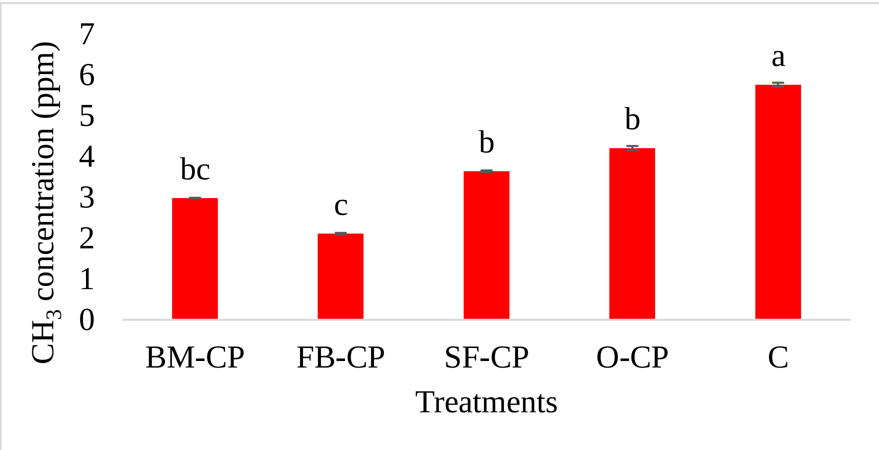


Fig. 6(a & b): CO_2 concentration (a) and CH_3 concentration (b). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

F. Grain Quality and Quantity

Growing of cover crops in wheat positively influence the grain protein content and yield. Faba bean legume followed by sunflower cover crop has observed considerably high amount of protein content while minimum was recorded in control (Figure 7a). Alternatively, there was increase in the grain yield of wheat with the faba bean cover crop followed by sunflower and brown mustard (Figure 7b)

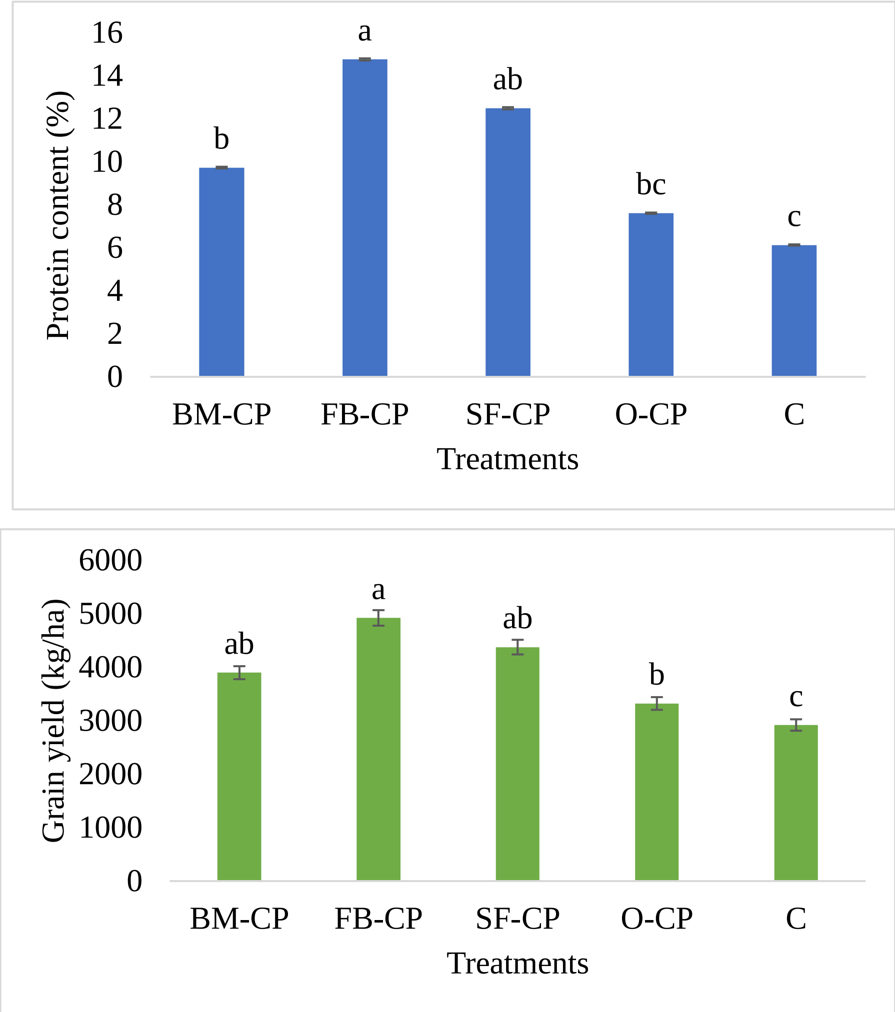


Fig. 7(a & b): Protein content and grain yield (b). Points show means, and error bars are model estimates of standard errors for comparison among means of the treatments. BM-CP = Brown mustard cover crop, FB-CP = Faba bean cover crop, O-CP = Oat cover crop and C = control (no cover crop).

G. Pearson Correlation among different soil building traits and weed parameters with grain quality and quantity

Pearson's correlation matrix among the soil building traits and weed parameters withgrain attributes of wheat is shown in Table 2. The results revealed strong significant positive correlation among the soil building attributes, i.e., soil fertility indices. With an increase in TOC content (%), total nitrogen (ppm) increased and improved properties like aggregate stability (%)and root density (mg/cm^3) (Table 2). On the other hand, weed parameters, weed biomass (kg/m^2) and weed cover (%) has strong negative influence on grain protein content (%) and grain yield (kg/ha) while weed suppression has strong positively affected the grain quality and quantity of wheat (Table 2). There was strong positive relationship between soil properties and grain protein content and yield of wheat. The increase in soil functions is directly proportional to the wheat grain quality and quantity whereas the increase in weed biomass and weed cover is inversely proportional to the soil and grain properties (Table 2).

Table 2: Relationship among weed traits with different soil building parameters and crop quality and quantity as influenced by various cover crops

	Weed biomass (kg/m²)	Weed cover (%)	Weed suppression	TOC (g/kg)	Total Nitrogen (ppm)	Aggregate stability (%)	Root density (mg/cm³)	Grain yield (kg/ha)	Protein content (%)
Weed biomass (kg/m²)	1								
Weed cover (%)	0.990035	1							
Weed suppression	-0.99071	-0.98382	1						
TOC (g/kg)	-0.37588	-0.37383	0.578476	1					
Total Nitrogen (ppm)	-0.27255	-0.27204	0.685186	0.985484	1				
Aggregate stability (%)	-0.39436	-0.39021	0.415411	0.982316	0.9897	1			
Root density (mg/cm³)	-0.82037	-0.96973	0.853574	0.891552	0.905581	0.935377	1		
Grain yield (kg/ha)	-0.98488	-0.92843	0.996063	0.988832	0.999778	0.990167	0.904717	1	
Protein content (%)	-0.83101	-0.73589	0.837811	0.985248	0.996541	0.976572	0.872043	0.996827	1

r value: 0.0 to 0.2—very weak fit, 0.2 to 0.4—weak fit, 0.4 to 0.7 –moderate fit, 0.7 to 0.9—strong fit, 0.9 to 1.0—very strong fit. LA = Leaf area, LAI = Leaf Area Index, WC = Weed cover, RD = Root density, TOC = Total Organic Carbon, TN = Total Nitrogen.

IV. DISCUSSION

Increased biomass, higher nutrient capture, and improved weed suppression were all linked to crops that showed a faster growth rate, and generated a bigger leaf area. These outcomes are predicted since several studies have shown that growth rate, leaf area, and LAI impact a plant's ability to compete with nearby species for resources (Reich et al., 2003, Caruso et al., 2020). Legumes had the highest weed suppression, which is consistent with prior research (Petchey & Gaston, 2006) that found alfalfa and clover to be the most weed suppressive when compared to wheat and barley. In our investigation,brown mustard and faba bean —which were also one of the cover crops which have given the leaf area, and leaf area index in wheat and were also very successful in suppressing weeds. Due to the rapid growth of brown mustard, as seen above, and possible allelopathic effects that prevent competing weedroots from growing. The aboveground competitiveness in oil seed crops have been shown to decrease weed populations in the spring when fertilizer inputs are minimal (Díaz et al., 2007, Abdalla et al., 2019),faba bean has frequently been demonstrated to be an effective crop for controlling weeds (Cortois et al., 2016, Caruso et al., 2020).

The best cover crops for pulling more nutrients from the environment were legumes. High biomass generating legumes, as faba bean in our study, can be especially useful as green manure for organically bound nutrients and soil fertility (Baets et al., 2007). However, we discovered that legumes had the largest amount of residual NO_3 in the soil at the end of the growing season. This suggests that although while legumes are very effective at absorbing N from the environment, because they get the majority of their N via N_2 fixation, they might not be the best crop to employ as a high fertilizer N usage efficiency crop for absorbing surplus mobile forms of N in the soil (Stokes et al., 2009, Macleod et al., 2013, Costanzo & Bàrberi, 2014).

The availability of phosphorus and potassium is maximum in the main crop when grown with legume cover crop(Londo, 1976). Similarly, effect of legume-based cover cropping has positively influenced the uptake of nutrients P and K by the crop grown under examination (Meyer et al., 2017). Soil phosphorus and potassium are the main nutrients for proper plant growth and soil nourishment (Angers &Mehuys, 1993) and growing of crops like alfalfa, brown mustard and clover in cover heighten up these availability of such nutrients (Keeney & Nelson, 1983, Nelson, 1983, Daryanto et al., 2018). This eventually result in microbial growth and sustainability in soil (Culman et al., 2012). Because cover crops like faba bean, brown mustard and clover offers a pool of nutrients that are bonded organically so theyserve as a main source for nutrient mineralization by soil microorganisms; soil total organic matter is an essential feature of soil organic carbon and nutrient cycling (Gardes& Bruns, 1993, White et al., 1990).

After one growing season, we found that, although there was little significant variation between cover crops on soil building (OM-C and N), there was a significant correlation between soil organic matter and leaf area, which in turn led to higher crop biomass production (Herlemann et al., 2011).This is probably because taller plants with bigger leaves have a greater potential for photosynthetic carbon and nitrogen accumulation in the soil, which may have been deposited there by root exudates and the release of carbon to soil microorganisms through photosynthetic processes (Fujimura et al., 2003, Borrell et al., 2017, Niu et al., 2018). Building soil OM-C and N pools, however, would take several years to develop (Hofer, 2013).

V. CONCLUSION

The study underscores the need for more empirical research to fully harness the potential of cover crops, as the use of functional crop features to predict their impact on different agroecosystem services is still in its early to maturity stages. The conducted experiment, which evaluated the impact of four cover crops on various ecosystem services of wheat, provides valuable insights.

The results of the study highlight the nuanced effects of different cover crops on aboveground traits, nutrient capture, weed suppression, soil building, and greenhouse gas emissions. Notably, legumes, exemplified by faba bean, demonstrate their prowess in nutrient capture, while mustards like brown mustard excel in weed suppression.

The findings contribute to the growing body of knowledge on how cover crops can be strategically employed to enhance specific aspects of agroecosystem services.

Moreover, the correlation analysis among different soil-building traits and weed parameters reveals intricate relationships that underscore the interconnected nature of these processes. The positive correlation between soil fertility indices and weed suppression emphasizes the multifaceted impact cover crops can have on the overall health and functionality of agroecosystems.

In the broader context of sustainable agriculture, the study's implications extend to the potential mitigation of greenhouse gas emissions, an essential consideration in the face of climate change. The identification of cover crops that positively influence gas fluxes, such as faba bean and brown mustard, suggests a dual benefit – improved agroecosystem services and reduced environmental impact. However, the research community must continue to delve into the vast diversity of cover crops and their potential applications, considering the complexity of agroecosystems.

CONFLICT OF INTEREST

There is no conflict of interest among the authors.

REFERENCES

[1]. Abdalla, M., Hastings, A., Cheng, K., Yue, Q., Chadwick, D., Espenberg, M., ... & Smith, P. (2019). A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. *Global change biology*, *25*(8), 2530-2543.

[2]. Baets, S. D., Poesen, J., Knapen, A., & Galindo, P. (2007). Impact of root architecture on the erosion-reducing potential of roots during concentrated flow. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *32*(9), 1323-1345

[3]. Bender, S. F., Wagg, C., & van der Heijden, M. G. (2016). An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. *Trends in ecology & evolution*, *31*(6), 440-452.

[4]. Blanco-Canqui, H., Shaver, T. M., Lindquist, J. L., Shapiro, C. A., Elmore, R. W., Francis, C. A., & Hergert, G. W. (2015). Cover crops and ecosystem services: Insights from studies in temperate soils. *Agronomy journal*, *107*(6), 2449-2474.

[5]. Blesh, J. (2018). Functional traits in cover crop mixtures: Biological nitrogen fixation and multifunctionality. *Journal of Applied Ecology*, *55*(1), 38-48.

[6]. Borrell, A. N., Shi, Y., Gan, Y., Bainard, L. D., Germida, J. J., & Hamel, C. (2017). Fungal diversity associated with pulses and its influence on the subsequent wheat crop in the Canadian prairies. *Plant and Soil*, *414*, 13-31.

[7]. Brust, J., Claupein, W., & Gerhards, R. (2014). Growth and weed suppression ability of common and new cover crops in Germany. *Crop Protection*, *63*, 1-8.

[8]. Carter, M. R., & Gregorich, E. G. (1993). Canadian Society of Soil Science. *Soil sampling and methods of analysis*.

[9]. Caruso, C. M., Maherali, H., & Martin, R. A. (2020). A meta-analysis of natural selection on plant functional traits. *International Journal of Plant Sciences*, *181*(1), 44-55.

[10]. Cortois, Roeland, Thomas Schröder-Georgi, Alexandra Weigelt, Wim H. van der Putten, and Gerlinde B. De Deyn. "Plant–soil feedbacks: role of plant functional group and plant traits." *Journal of Ecology* 104, no. 6 (2016): 1608-1617.

[11]. Costanzo, A., &Bàrberi, P. (2014). Functional agrobiodiversity and agroecosystem services in sustainable wheat production. A review. *Agronomy for sustainable development*, *34*, 327-348.

[12]. Culman, S. W., Snapp, S. S., Freeman, M. A., Schipanski, M. E., Beniston, J., Lal, R., ... & Wander, M. M. (2012). Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Science Society of America Journal*, *76*(2), 494-504.

[13]. Daryanto, S., Fu, B., Wang, L., Jacinthe, P. A., & Zhao, W. (2018). Quantitative synthesis on the ecosystem services of cover crops. *Earth-Science Reviews*, *185*, 357-373.

[14]. Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., & Robson, T. M. (2007). Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences*, *104*(52), 20684-20689.

[15]. Emmerson, M., Morales, M. B., Oñate, J. J., Batary, P., Berendse, F., Liira, J., ... & Bengtsson, J. (2016). How agricultural intensification affects biodiversity and ecosystem services. In *Advances in ecological research* (Vol. 55, pp. 43-97). Academic Press.

[16]. Friberg, H., Edel-Hermann, V., Faivre, C., Gautheron, N., Fayolle, L., Faloya, V., ... & Steinberg, C. (2009). Cause and duration of mustard incorporation effects on soil-borne plant pathogenic fungi. *Soil Biology and Biochemistry*, *41*(10), 2075-2084.

[17]. Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The challenge of feeding the world. *Sustainability*, *11*(20), 5816.

[18]. Fujimura, M., Minami, Y., Watanabe, K., &Tadera, K. (2003). Purification, characterization, and sequencing of a novel type of antimicrobial peptides, Fa-AMP1 and Fa-AMP2, from seeds of buckwheat (Fagopyrum esculentum Moench.). *Bioscience, biotechnology, and biochemistry*, *67*(8), 1636-1642.

[19]. Gaba, S., Lescourret, F., Boudsocq, S., Enjalbert, J., Hinsinger, P., Journet, E. P., ... & Ozier-Lafontaine, H. (2015). Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. *Agronomy for sustainable development*, *35*, 607-623.

[20]. Gardes, M., & Bruns, T. D. (1993). ITS primers with enhanced specificity for basidiomycetes-application to the identification of mycorrhizae and rusts. *Molecular ecology*, *2*(2), 113-118.

[21]. Herlemann, D. P., Labrenz, M., Jürgens, K., Bertilsson, S., Waniek, J. J., & Andersson, A. F. (2011). Transitions in bacterial communities along the 2000 km salinity gradient of the Baltic Sea. *The ISME journal*, *5*(10), 1571-1579.
[22]. Hofer, U. (2013). Getting to the bottom of Cyanobacteria. *Nature Reviews Microbiology*, *11*(12), 818-819.
[23]. Jin, X., Wang, J., Li, D., Wu, F., & Zhou, X. (2019). Rotations with Indian mustard and wild rocket suppressed cucumber Fusarium wilt disease and changed rhizosphere bacterial communities. *Microorganisms*, *7*(2), 57.
[24]. Keeney, D. R., & Nelson, D. W. (1983). Nitrogen—inorganic forms. *Methods of soil analysis: Part 2 chemical and microbiological properties*, *9*, 643-698.
[25]. Lefebvre, M., Leblanc, M. L., & Watson, A. K. (2018). Seed dormancy and seed morphology related to weed susceptibility to biofumigation. *Weed Science*, *66*(2), 199-214.
[26]. Londo, G. (1976). The decimal scale for releves of permanent quadrats. *Vegetatio*, *33*, 61-64.
[27]. Macleod, C. K. J., Humphreys, M. W., Whalley, W. R., Turner, L., Binley, A., Watts, C. W., ... &Haygarth, P. M. (2013). A novel grass hybrid to reduce flood generation in temperate regions. *Scientific reports*, *3*(1), 1683.
[28]. Meyer, S. T., Scheithe, L., Hertzog, L., Ebeling, A., Wagg, C., Roscher, C., & Weisser, W. W. (2017). Consistent increase in herbivory along two experimental plant diversity gradients over multiple years. *Ecosphere*, *8*(7), e01876.
[29]. Nelson, D. W. (1983). Determination of ammonium in KCl extracts of soils by the salicylate method. *Communications in Soil Science and Plant Analysis*, *14*(11), 1051-1062.
[30]. Newbold, T., Hudson, L. N., Hill, S. L., Contu, S., Lysenko, I., Senior, R. A., ... & Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, *520*(7545), 45-50.
[31]. Niu, Y., Bainard, L. D., May, W. E., Hossain, Z., Hamel, C., & Gan, Y. (2018). Intensified pulse rotations buildup pea rhizosphere pathogens in cereal and pulse based cropping systems. *Frontiers in Microbiology*, *9*, 1909.
[32]. Ordóñez-Fernández, R., de Torres, M. A. R. R., Márquez-García, J., Moreno-García, M., & Carbonell-Bojollo, R. M. (2018). Legumes used as cover crops to reduce fertilisation problems improving soil nitrate in an organic orchard. *European Journal of Agronomy*, *95*, 1-13.
[33]. Perrone, S., Grossman, J., Liebman, A., Sooksa-nguan, T., & Gutknecht, J. (2020). Nitrogen fixation and productivity of winter annual legume cover crops in Upper Midwest organic cropping systems. *Nutrient Cycling in Agroecosystems*, *117*, 61-76.
[34]. Petchey, O. L., & Gaston, K. J. (2006). Functional diversity: back to basics and looking forward. *Ecology letters*, *9*(6), 741-758.
[35]. Philip Robertson, G., Gross, K. L., Hamilton, S. K., Landis, D. A., Schmidt, T. M., Snapp, S. S., & Swinton, S. M. (2014). Farming for ecosystem services: An ecological approach to production agriculture. *BioScience*, *64*(5), 404-415.
[36]. Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical transactions of the royal society B: biological sciences*, *365*(1554), 2959-2971.
[37]. Pretty, J., & Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of botany*, *114*(8), 1571-1596.
[38]. Reich, P. B., Wright, I. J., Cavender-Bares, J., Craine, J. M., Oleksyn, J., Westoby, M., & Walters, M. B. (2003). The evolution of plant functional variation: traits, spectra, and strategies. *International Journal of Plant Sciences*, *164*(S3), S143-S164.
[39]. Saleem, M., Pervaiz, Z. H., Contreras, J., Lindenberger, J. H., Hupp, B. M., Chen, D., ... & Twigg, P. (2020). Cover crop diversity improves multiple soil properties via altering root architectural traits. *Rhizosphere*, *16*, 100248.
[40]. Sharma, R., Sindhu, S., & Sindhu, S. S. (2018). Suppression of Alternaria blight disease and plant growth promotion of mustard (Brassica juncea L.) by antagonistic rhizosphere bacteria. *Applied Soil Ecology*, *129*, 145-150.
[41]. Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., ... &O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy journal*, *97*(1), 322-332.
[42]. Stokes, A., Atger, C., Bengough, A. G., Fourcaud, T., & Sidle, R. C. (2009). Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant and soil*, *324*, 1-30.
[43]. Teasdale, J. R. (1996). Contribution of cover crops to weed management in sustainable agricultural systems. *Journal of production agriculture*, *9*(4), 475-479.
[44]. Teasdale, J. R., Brandsaeter, L. O., Calegari, A. D. E. M. I. R., Neto, F. S., Upadhyaya, M. K., & Blackshaw, R. E. (2007). Cover crops and weed management. *Non-chemical weed management: principles, concepts and technology*, 49-64.
[45]. Thorup-Kristensen, K., Magid, J., & Jensen, L. S. (2003). Catch crops and green manures as biological tools in nitrogen management in temperate zones. *Advances in agronomy*, 227-302.
[46]. Tilman, D. (1999). Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proceedings of the national Academy of Sciences*, *96*(11), 5995-6000.
[47]. Tribouillois, H., Fort, F., Cruz, P., Charles, R., Flores, O., Garnier, E., &Justes, E. (2015). A functional characterisation of a wide range of cover crop species: Growth and nitrogen acquisition rates, leaf traits and ecological strategies. *PLoS one*, *10*(3), e0122156.
[48]. Wendling, M., Büchi, L., Amossé, C., Sinaj, S., Walter, A., & Charles, R. (2016). Influence of root and leaf traits on the uptake of nutrients in cover crops. *Plant and Soil*, *409*, 419-434.

ISSN No:-2456-2165

[49]. White, T. J., Bruns, T., Lee, S. J. W. T., & Taylor, J. (1990). Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. *PCR protocols: a guide to methods and applications*, *18*(1), 315-322.
[50]. Wittwer, R. A., Dorn, B., Jossi, W., & van der Heijden, M. G. (2017). Cover crops support ecological intensification of arable cropping systems. *Scientific reports*, *7*(1), 41911.
[51]. Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., & Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecological economics*, *64*(2), 253-260.