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Role of Green Manuring in Improving Soil Fertility and Crop Yield

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ABSTRACT

Green manuring is a very ancient though becoming an important agronomic practice that plays a significant role in improving the soil fertility as well as crop production in the sustainable agricultural systems. It involves planting and incorporation of specific species of plants, mostly legumes in the soil to provide organic matters as well as nutrients necessary in the soil. The growing fear of soil erosion, the declining soil fertility, as well as the adverse impact of chemicals on the environment due to the high usage of the fertilizers have resulted in the renewed emphasis on green manuring as a more sustainable means of keeping the soil healthy. This process supplements the physical, chemical, and biological properties of soil through the incorporation of organic carbon into soil, which increases the availability of nitrogen to soil by reacting with soil biology and doubles soil structure and generation of microbial activity. Moreover, green manuring will assist in increasing the water retention, soil erosion and nutrient cycling, which will consequently lead to high crop produce and long term sustainability of agriculture. Extensive amount of research in different agro-ecological areas demonstrate that green manuring leads to high level of crop performance particularly in cropping systems where peonage crops predominantly feature. The paper is concerned with the significance of green manuring to increase the soil fertility and crop yield with keen interests of the mechanisms, the benefits, and significance of green manuring in the modern sustainable farming.

Introduction

The food security and agricultural production in the developing countries particularly relies on the soil fertility as it is one of the key determinants of agriculture since agriculture is the prime source of livelihood in the rural setting. The resulting consequences of the intensive agricultural practices of the last few decades have included the extreme soil health conditions, including nutrient depletion, soil structure degradation, and organic matter disruption, along with the reduction of the microorganism activity (Lal, 2015). All these challenges have preconditioned the world concern with the sustainability of the traditional agricultural systems and ignited a new interest in the low-input and ecologically friendly approaches to soil management. One of these practices is green manuring which has come to be known as a good practice in restoring the lost soil fertility and boosting crop production without necessarily leading to numerous environmental degradations (Giller, 2001).

Green manuring may be termed as a method of growing crops and planting them in the soil when they are small in age so as to boost the nutrient level and physical well-being of the soil. It is known that the plants that fix nitrogen in the atmosphere are green manure plants (e.g. sesbania, crotalaria, vica, trifolium) particularly due to symbiosis with rhizobia bacteria (Peoples et al., 2009). As the biomass of the green manure decomposes, the biologically stored nitrogen is released to the following crop and this renders the application of synthetic nitrogen fertilizers less dependent. Other than nitrogen enrichment, the green manuring contributes a significant amount of organic matter to the soil that is required to maintain soil fertility and prolonged productivity (Brady and Weil, 2016).

The importance of organic matter and its influence on the soil fertility cannot be stressed enough, as organic matter has a direct impact on the soil structure, water-holding capacity, cation exchange capacity and nutrient availability. Green manuring increases the soil organic carbon which encourages the aggregate stability and reduces soil compaction thereby

favouring the development of roots and increasing aeration (Six et al., 2002). It also enhances the infiltration and minimizes surface runoffs besides making soils more erosion and moist resistant. These benefits are particularly important to rainfed and semi-arid agricultural systems where water is a limiting production factor (FAO, 2017).

There is great biological effect of green manuring on soil besides physical one. Fresh organic residues also contribute to the number of the microbes that are also involved in the mineralization and cycling of nutrients (Gregorich et al., 2001). A high activity of the microbes enhances the availability of macro- and micro nutrients e.g. phosphorus, sulfur and zinc that are normally rendered inaccessible in the degraded soils. It has also been found that the soil treated with green manure contains a high amount of enzyme and microbial biomass carbon in comparison to the soils that are treated with the inorganic fertilizers alone(Kumar and Goh, 2000). This biological environment of the soils makes the crops grower and contributes to stability of the yield.

Green manuring is also applicable in the same case with the integrated nutrient management systems since it increases the performance of the fertilizers. Green manure can be used in conjunction with chemical manure and help eliminate the loss of nutrients due to leaching and volatilization and also the results of crops can meet demands (Palm et al., 2001). Such a combination technique not only leads to more harvesting of crops, but also makes production cheaper and less pollution of the environment, which could arise because of over-use of fertilizers. Green manuring, thus, can be applied to the notion of sustainable and climate-smart agriculture.

Green manuring has been widely documented as a good way of crop yield mitigation in various types of cropping systems. An area where green manuring can be reported to make a substantial difference in increasing the volume of grain yield, straw yield and overall biomass yield in a cereal based rotation such as rice-wheat and maize-legume rotation (Yadvinder-Singh et al., 2005). The cause of the yield benefits is believed to be improved nitrogen availability, improved growth of roots and enhanced moisture retention of soil. It has been found that the use of pre-cultivated crops before transplant like Sesbania aculeata to replace a large portion of the suggested quantity of nitrogen fertilizer thereof in rice cultivation did not harm the yield (Buresh and Reddy, 2001).

Green manuring ensures that the long term soil fertility and sustainability are improved by preventing the mining of nutrients and by reclaiming soils that are degraded besides increasing yield. Agricultural practices with repeated without organic fertilizer tend to cause a decline in the amount of organic matter in the soil with long-term negative effects on the long term soil productivity. Green manuring replenishes the organic stores and balances the supply of nutrients and therefore, sustains crop production over the long-run (Tilman et al., 2002). This augments green manuring particularly to the small holder farmers who have easy access to chemical fertilizers as well as increased cost of inputs.

The modern day agricultural practice is also applicable to green manuring as a result of the environmental advantages that it comes with. Green manuring minimizes emission of green house gases by way of manufacturing and application of synthetic manure (Smith et al., 2008). It also increases the carbon sequestration of the soil, which aid in reduction of climate change. Moreover, the green manure crops can also minimize the increase of weeds, interference in pathogen and pathogen cycles, and enhance biodiversity in agro-ecosystems hence resulting in ecological balance (Drinkwater et al., 1998).

There are numerous benefits that have been witnessed as a result of the adoption of green manuring but lack of awareness, competition over land, and economic benefits at the immediate levels are some of the numerous factors that have seen its adoption fail in most places. However, due to the increasing popularity of the concept of sustainable agriculture and the need to restore the health of soils, the issue of green manuring is now subject to new interest among researchers, policy-makers, and agricultural communities. This would be required in determining the role it could play in improving food security in designing effective soil management strategies that would make the soils remain fertile and yield crops, and safeguard the natural resources.

Literature Review

Green manuring is one principle that has largely been studied on as a sustainable mode of soil management to enhance the soil fertility and crop production across agro-ecological zones. The initial agronomic investigations were basing on the factuality of organic amendments to hold soils healthy in agro-ecosystems in which incessant cultivating and exploitation of chemical fertilizers had led to the degeneration of soils and consequent declining yields. The concept of green manuring, which can be described as the cultivation and incorporation of green biomass to the soil, has been proposed as the major contributor of organic matter and nutrients that stimulate the short-term crop productivity and the long-term soil sustainability (Brady, and Weil, 2016).

A lot of literature has been published on the significance of green manuring in improving the chemical characteristics of the soil particularly the soil nitrogen status. Biological nitrogen fixation Biological fixation of nitrogen has contributed to the development of research on leguminous green manure crop such as Sesbania, Crotalaria, Vicia and Trifolium. It has been revealed that the crops can accumulate high concentration of atmospheric nitrogen and a nitrogen concentration of between 40 to above 200 kg N ha-1 by species, soil and climatic conditions (Peoples et al., 2009). The decomposition of the green manure residues as they are incorporated into the soil gives the soil the nitrogen in forms that are available to plants and therefore improves the nitrogen status of the soil in future. Research conducted on cereal systems has also gone on to indicate that green manuring can replace 25-60 percent of the recommended level of nitrogen fertilizer without losses in yield (Buresh and Reddy, 2001; Yadvinder-Singh et al., 2005).

Besides increasing the nitrogen level, green manuring has also been noted to increase the supply of other vital nutrients like phosphorus, potassium, sulfur and micronutrients. The resulting organic acids can mobilise the fixation committed to calcareous and acidic soils and thus, the phosphorus that would otherwise be inaccessible is mobilised by the organic acids generated during the process of decomposing the residues (Palm et al., 2001). Other studies have established that the availability of phosphorus in the soil increased after addition of green manures and also the crops were able to take in more nutrients particularly in the soils that had been drained of most nutrients (Kumar and Goh, 2000). This is because nutrient-enhancing ability of green manuring has led to the emergence of the importance of adopting green manuring as a nutrient management tool in an integrated nutrient management structure.

The role of green manuring in the carbon dynamics and soil organic matter has been paid considerable attention by research in soil science. The organic matter of the soil is one of the main parameters which determine whether the soil is fertile and its decline is one of the major constraints of sustainable production of foods globally. Many long-term field experiments have proven that a regular utilization of the green manure crops could significantly increase the quantity of soil organic carbon, decrease the soil framework and enhance the retention of nutrients (Six et al., 2002; Lal, 2015). The growth of the roots is improved as the growth in the organic matter leads to the increase of porosity and consequently reduces the bulk density in the soil, thereby increasing the soil aggregation. These shifts in the physical properties of soil have been linked to higher crop production and drought and water stress resistance in particular of the rainfed agricultural systems (FAO, 2017).

Green manuring has also a significant impact on the soil biological properties and these properties are currently being regarded as significant indicators of soil health. The addition and fresh organic residues encourage the activities of the microorganisms in the soil since it harbours energy and matter that can be used to proliferate. It has been observed that when green manure was added to the soils, there were significant increases in the microbial biomass carbon, enzymatic activities and soil respiration rate (Gregorich et al., 2001). Increased microbial activity enhances the rate of nutrient mineralization and enhances the harmonisation of nutrients and crop needs thereby, reducing the loss of nutrients. The comparative researches of organic and conventional systems have indicated a high degree of biological diversity and functional stability of soils fed on green manures in comparison with soils fed on inorganic fertilizers only (Drinkwater et al., 1998).

The interaction between fertilizer use performance on the one hand and green manuring on the other hand has been a popular literature issue. It has been found that combined nutrient management systems employing green manure in addition to chemical fertilizers can result in a better utilization of the nutrients in the soil and maintain the yield of crops unchanged or even increased. According to Palm et al (2001), the combination of organic and inorganic sources of nutrients increased the patterns of nutrient release with time and reduced the loss of nitrogen through leaching and volatilization. These findings suggest that green manuring is not only the process that enhances the soil fertility, but also the process that maximizes the use of fertilizers, which is an element of the cost-effective, socially and environmentally responsible agricultural systems.

It has been established that through green manuring the crop yield of a high number of crops and crop systems has been affected. It has also been seen that introduction of green manure crop such Sesbania aculeata in rice-based systems prior to transplantation can help increase grain production, straw production and even in the absorption of nitrogen (Buresh et al., 2001). All these yield-enhancing effects have been observed to be best when applied in wheat, maize, sorghum and vegetable crops particularly when there is regular application of green manuring during multiple seasons (Yadvinder-Singh et al., 2005). This kind of increased yields has been attributed to an increase in terms of availability of nutrients, the capacity of the soil to retain more moisture or improved root growth.

Long term research has shown that there should be manuring of the green lands so as to achieve stability and sustainability in their yields. Frequent agriculture by the use of non-organic fertilizers is likely to lead to yielding of diminishing crops due to mining of the nutrients and soil erosion. On the other hand, the cropping systems that involve the use of green manure have been discovered to be more consistent in terms of the yield over the years and also include better signs of soil fertility (Tilman

et al., 2002). This kind of a long term perspective would be particularly relevant to smallholder farming systems where the livelihood security of such systems would be achieved by sustaining soil productivity using a limited number of external inputs.

Green manuring has not been left behind in the literature and environmental benefits of green manuring have been discussed extensively. Increased use of synthetic manure has been linked to emission of the green house gases, water pollution and soil acidification. Green manuring reduces the fertilizer chemical usage and also contributes to the reduction of nitrous oxide emission, as a result of the high efficiency of nitrogen usage (Smith et al., 2008). In addition, there is enhanced carbon sequestration due to high carbon organic matter brought about by use of green manure making green manuring a climate-smart farming practice.

It is known that the green manuring is significant in the regulation of the weeds and pests. Some of the works have unveiled that the heavy green manure plants discourage the growth of the weed by competing with the light, nutrients and space and reduce the weed seed banks (Teasdale, 1996). Moreover, the pest and disease cycle can be broken by diversification of the cropping systems through the use of the green manure that will result in reduced reliance on the pesticides and resistance to the agro-ecosystems (Altieri, 1999).

Despite numerous evidences on the benefits of green manuring, it remains very low in majority of places. Researchers have attributed competition on land and labor demands and sluggishness in economic returns as some of the impediments to adoption (Giller et al., 2009). However, the recent studies also indicate the fact that green manuring is among the most viable ways to engage in sustainable agriculture bearing in mind such long-term effects as soil fertility restoration, crop yield stability, and the reduction of input costs.

Green manuring has certain prospects especially in developing countries like south Asia since it is cheap and can be adapted to the local farming systems. Studies conducted in Pakistan and India have shown that the application of green manuring may cause a strong positive impact on the fertility of soil and crop production in rice-wheat and maize based systems that represent the primary mode of agriculture in the area (Yadvinder-Singh et al., 2005). The results make green manuring a topical issue of the effective solution to the issue of low soil fertility and food security.

Overall, literature supports the role of green manuring as a multi-faceted soil management technique, which improves the chemical, physical, and biological properties of the soil and improves crop production and stability. The constant outcomes in the diverse conditions and cropping systems presented in the modern day agricultural research and practice underscores its role in the same. It is necessary to note however that further research is necessary to streamline the choice of the species, feeding time, and compatibility with the current farming technologies so that one can be capable of gaining the greatest benefits in the evolving agro-climate conditions.

Methodology

Research Design

The research design applied in the study was the analytical and experimental research design in which the impact of green manuring in improving soil fertility and crop yield was tested. Primary data were generated in the natural agro-climatic conditions by means of field-based approach. The experimental design provided the ability to make a systematic comparison of the plots in case of a green manure treatment and in the case when the plots are managed by the traditional fertilization strategies. The design used was to establish the cause and effect relations of the green manuring practices on the changes observed in the indicators of soil fertility and the parameters of crop yield.

Study Area

The experiment was conducted in a farming field that had semi-arid to sub-humid climatic conditions that characterise large cereals producing regions of Punjab, Pakistan. Summer is hot with an average of 500 to 700 mm/per year of rainfall with most of the rainfall being received in the monsoon and winter is mild. The soils of the study area are either predominantly alluvial, loam texture and moderate fertility. The reason behind selecting this area was due to the nature of the predominantly cereal based farming systems and the overuse and constant cropping of the soils which has been greatly influenced by the chemical fertilizers.

Design of Experiments and Interventions

Randomized complete block design (RCBD) was employed to eliminate the influence of the spatial variation of soil characteristics. The experiment involved three treatments that were replicated. These were: (i) the control plot of which there

was no green manuring and which received the doses of recommended chemical fertilizers, (ii) green manuring alone and (iii) integrated treatment in which case there was the use of green manuring and lesser doses of recommended chemical fertilizers were applied. The size of all the experimental plots was uniform in order to perform consistency in agronomic operations.

Sesbania aculeata is a leguminous crop, and Sesbania aculeata was selected as a green manure as the crop possesses a large capacity of biomass generation, high growth rate as well as it has the ability to fix nitrogen. The green manure was sown prior to the actual crop and the application in the ground took place at the time when the crop was in flower by the traditional means of tillage. Approximately 40-45 days after sowing, incorporation was made to maximize the biomass of the plant as well as add to the nutrients.

Crop Management Practices

Following the introduction of green manure, a principle test crop (rice or wheat according to the appropriateness of seasons) was planted, as well, according to the suggested agronomics. All the plots received equal amounts of irrigation, weed control and pest control to ascertain that the difference in yields could be much as a result of treatment effects. Specifications of treatment were applied to use chemical fertilizers, and reduced amounts of nitrogen to integrated plots were applied to find out the possibility of fertilizer replacement of green manuring.

Soil Sampling and Analysis

In order to establish alterations in the soil fertility status, the soil samples in each plot before the experiment started and after harvesting the crops were collected. The sample of the composite soil samples was sampled using a soil auger at a depth of 0-15 cm and dried in air and sieved before being exposed to the laboratory using the conventional soil analysis techniques.

Some of the parameters of the soil which were analyzed included the soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, soil pH and bulk density. To determine the soil organic carbon, the Walkley-Black method was employed whereas to determine the total nitrogen in the soil, Kjeldahl method of digestion was applied. Olsen method was used in the analysis of phosphorus available and flame photometry in the analysis of potassium content. These parameters were chosen because they were required to provide a complete measure of soil chemical and physical fertility.

Crop Yield and Yield Components Measurement

The physiological maturity time was used to take the data of crop yield. The parameters to be measured were the plants height, number of tillers or branched per plant, quantity of grains or biomass produced and the total above ground biomass. The one and the half grain of adjusted standard moisture content were obtained, obtained and presented in terms of hectare, from each of the plots. These yield components were used in order to establish the effect of green manuring on the crop productivity directly.

Data Analysis

The acquired data were evaluated statistical data with the help of the appropriate statistical software. Significant differences of treatments on soil fertility parameters and crop yield characteristics were established with the help of analysis of variance (ANOVA). The mean comparisons were done at a level of significance of 5 percent and the least significant difference (LSD) test was employed. Correlation analysis was also used to determine relations between soil fertility indicators and crop yield as well.

Validity and Reliability

In order to ensure validity and reliability of the findings, the standardized experimental procedures and laboratory methods were followed in the process of conducting the study. The replication and randomization reduced the error and bias in the experiments. The use of calibrated instruments and known methods in order to measure soil and yield was a way of ensuring the necessary consistency and accuracy.

Ethical and Environmental Responsibilities

Ethical research was carried out by the researcher by ensuring that there are responsible ways of land use and causing minimal environmental disruption. Green manuring also contributes to the sustainable principles of agriculture because it assists in the conservation of the soil, reduced use of chemical fertilizers, and assistance in the environmental protection.

Data Analysis and Findings

The data collected in the field experiment was to be analyzed in order to establish the influence of green manuring on the parameters of soil fertility and crop yield. Comparison of the control plots, green manuring treatments, and integrated nutrient management treatments was carried out through the statistical results. The results are a good pointer to the contribution made by the practice of green manuring in enhancing the well being of the soils and ensuring that crop yield.

Change in Soil Organic carbon

The essential parameters of soil fertility and sustainability are organic carbon in the soil. It was found that the content of organic carbon in soil was immense in plots where green manuring was practiced as compared to the control treatment. It was relatively well uniformed before the experiment with the level of soil organic carbon in all the plots thereby similarity in the baseline soil condition. However, after harvest, the content of organic carbon in the plots green-manured increased significantly as a result of new biomass placed in the soil.

The increase in soil organic carbon was greatest in the plots that were receiving treatment with green manuring alone and then the integrated treatment. However, on the contrary, there was a very slight improvement in the control plots that were performed with the chemical fertilizers only. The consequent increase in the organic carbon leads to the degradation of the green manure biomass, which lead to the addition of the organic residues and to the activity of the microorganisms. The findings support the fact that green manuring is useful in the restoration of the soil organic matter, which is normally debilitated through continuous intensive cultivation.

Table 1: Effect of Green Manuring on Soil Organic Carbon (%)

Treatment	Before Experiment	After Harvest
Control (Chemical Fertilizer)	0.54	0.56
Green Manuring	0.55	0.72
Green Manuring + Reduced Fertilizer	0.54	0.68

Effect on Soil Nitrogen Content

The availability of soil nitrogen had a significant reaction to green manuring treatments. In statistical analysis, it was noted that the total nitrogen concentration of the soil significantly rose in plots that contained incorporation of the leguminous green manure. This growth has been contributed immensely by biological fixation of nitrogen by the green manure crop and subsequent release of nitrogen upon decomposition of the residue.

The integrated treatment was also found to use its nitrogen efficiently as the treatment had higher levels of nitrogen as compared to the control even though the treatment received less chemical fertilizer. This observation underscores the potential of green manuring as a substitute of fertilizers. Conversely, the concentration of nitrogen in the control plots did not change much indicating that there were higher losses of nitrogen and reduced retention of nutrients when single fertilizer of chemical origin was used.

Table 2: Effect of Green Manuring on Soil Total Nitrogen (%)

Treatment	Total Nitrogen (%)
Control	0.042
Green Manuring	0.061
Green Manuring + Reduced Fertilizer	0.057

Availability of Phosphorus and Potassium

Green manuring contributed tremendously in the supply of phosphorus and potassium in the soil. The growth of phosphorus was greater on green-manured plots which can be explained by the decomposition of organic acids and consequently, phosphorus was more readily soluble. Likewise, there was an increase in the availability of potassium, the cation exchange capacity was increased by the increase in organic matter content.

The integrated treatment was always better than the control which showed that the overall nutrient availability was improved by the green manuring and also showed that the efficiency of nutrient cycling was also increased as a result of

green manuring. These results underscore the importance of green manuring not just in the enrichment of soil with nitrogen, but also in general improvement of the soil fertility.

Table 3: Effect of Green Manuring on Available Soil Nutrients

Treatment	Available P (mg kg^{-1})	Available K (mg kg^{-1})
Control	7.8	121
Green Manuring	11.4	146
Green Manuring + Reduced Fertilizer	10.6	139

Changes in Soil Physical Properties

Green manuring had a positive effect on the physical properties of soil especially the bulk density. The use of organic biomass decreased the compaction of soil and enhanced the structure of soil. Green-manured plots would show lower values of bulk density and this was because soils had a better porosity and aeration.

The soil structure is also enhanced bestowing improved penetration of roots, water uptake, and water retention which is crucial in the growth of crops. The control treatment exhibited relatively greater bulk density, which shows bad physical conditions of the soil in the case of the continuous use of chemical fertilizers.

Table 4: Effect of Green Manuring on Soil Bulk Density (g cm^{-3})

Treatment	Bulk Density
Control	1.42
Green Manuring	1.29
Green Manuring + Reduced Fertilizer	1.31

Crop Yield and Yield Components

The data of crop yields demonstrated that there are considerable differences in treatments. The use of green manuring in farming techniques was able to significantly enhance the yield as well as the total biomass of grain in contrast to the control. The integrated treatment and green manuring alone recorded the highest and second highest grain yields respectively. The treatment that yielded the lowest was the control treatment and this is indicative of the shortcomings of complete dependence of chemical fertilizers to maintain productivity.

Better nutrient availability, better soil retention through moisture and better root development can be viewed as the explanations of better yield performance in green-manured plots. The components of yield, including plant height, the number of tillers, and the production of biomass was also better in green-manured treatments indicating general improvement of the crop vigor.

Table 5: Effect of Green Manuring on Crop Yield

Treatment	Grain Yield (t ha^{-1})	Biomass Yield (t ha^{-1})
Control	3.42	7.8
Green Manuring	4.28	9.6
Green Manuring + Reduced Fertilizer	4.45	10.1

Statistical Significance of Treatments

The results of the analysis of variance (ANOVA) proved that the differences in soil fertility parameters and crop yield that were observed between the treatments were statistically significant at the 5% level. Mean comparison by the LSD test also indicated that the manuring treatments (that were green) were significantly different to the control in most of the variables measured. These findings confirm the validity of the experimental results and the effect of using green manuring as an effective management practice in managing the soil fertility.

Correlation Coefficients between Soil Fertility and Crop Yield

The correlation analysis indicated that there was a positive strong relationship between soil organic carbon, total nitrogen and crop yield. The increased level of organic carbon was linked to increased available nutrients and enhanced yield performance. Equally, larger nitrogen levels had significant positive relationship with the yield of the grain, which also illustrated that the crop had a good utilization of the nitrogen provided by the green manuring process.

The integrated characteristics of soils in these relationships indicate that soil fertility enhancement by green manuring is characterized by improvements in chemical and physical properties of soil which work together to achieve high crop yields.

Summary of Findings

As observed in this study, there is a clear evidence that green manuring is very effective in the enhancement of the soil fertility because it improves the levels of organic carbon, nitrogen content, nutrient availability, and physical characteristics of the soil. These enhancements result in enhanced crop yields and improved yield components relative to the traditional chemical fertilizer activities. Combined application of green manuring and less used chemical fertilizers input was the most effective treatment which had both productivity and sustainability advantages.

In general, the evidence allows concluding that green manuring is a sustainable agronomic practice that has a potential of enhancing soil health, boosting crop production, and decreasing the use of synthetic fertilizers.

Discussion

The results of this paper show clearly the beneficial effect of green manuring in enhancing soil fertility and crop productivity in supporting the ever-increasing literature supporting sustainable nutrient management strategies. The pronounced rise in the content of soil organic carbon in green-manured plots supports the previous data that the introduction of new plant biomass increases the content of the soil organic matter and makes the soil structure better (Six et al., 2002; Lal, 2015). Higher levels of organic carbon enhance superior soil aggregation, better moisture retention and nutrient holding capacity all of which are essential in sustainable crop production. The fact that the enhancement of organic carbon was relatively small when using only the chemical fertilizers indicates the weaknesses of inorganic fertilizer in preserving the long-term soil health.

Biological fixation of nitrogen by leguminous green manure crops is the main factor in the improvement of the green-manured soils in terms of nitrogen. The result is related to other studies that have found significant nitrogen contributions by the use of green manures, which decreases the reliance of synthetic nitrogen fertilizers (Peoples et al., 2009; Giller, 2001). The integrated treatment, a combination of the green manuring and lesser chemical fertilizer input, had attained the same or greater nitrogen as it had been attained during the full chemical fertilization. That is why green manuring can be used to replace mineral fertilizers at least to some extent and preserve the fertility of the soil and crop yield.

The fact that phosphorus and potassium became more accessible also speaks in favor of the multifunctional role of green manuring in the cycling of nutrients. Organic acids that were released by the decomposing green manure residues probably increased the solubility of nutrients and decreased nutrient fixation within the soil, which increased nutrient availability to crops (Palm et al., 2001). These findings are in line with the previous studies that have shown organic amendments improve the efficiency of macro and micronutrient acquisition by crops (Kumar and Goh, 2000). Plant improvement is especially important where the soils have been affected by a long history of using chemical fertilizers thus creating nutrient imbalances.

The decrease in the soil bulk density of green-manured plots indicates the increase in the soil physical properties that are important in the growth of the roots and absorption of water. Enhanced soil structure leads to increased aeration and penetration of roots finally leading to increased crop growth and production. Green manure incorporation has reported similar improvements in the physical conditions of the soil in long-term field studies (FAO, 2017). These material enhancements augment the chemical and biological advantages of green manuring and bring out the holistic influence of green manuring on the soil health.

Further confirmation of the success of green manuring as a sustainable agronomic innovation is crop yield output. The high-yield of the same in green-manured and integrated treatments justifies results of previous research in the context of cereal based cropping systems, specifically in rice-wheat rotations (Yadvinder-Singh et al., 2005). The enhanced performance of the integrated treatment shows that a mixture of green manuring and a decreased use of chemical fertilizers is the most efficient method of making nutrients available and improving the use of fertilizers. This will not only increase yields but will also help lower the cost of production and also minimize the environmental hazards caused by high fertilizer application.

A positive relationship between the indicators of soil fertility and crop yield also supports the interdependence between soil health and crop productivity. The relationship between higher soil organic carbon and nitrogen content and higher crop yields were found to be very strong, implying that the enhancement of soil fertility by green manuring has a direct proportional relationship with the agricultural output. The results are in line with sustainable agriculture systems that focus on soil organic matter as the main productivity and resilience driver (Tilman et al., 2002).

On the whole, the findings of the given research are very consistent with the literature and reflect the empirical data about the feasibility of green manuring implementation in modern agribusiness. Green manuring provides a cheap and environmentally friendly solution to the problem of maintaining crop production in the context of Pakistan and other poorer nations where the problem of soil fertility degradation and increasing input prices is an issue of concern.

Conclusion

The current research comes to conclusion that green manuring has a major and complex role in increasing soil fertility and crop yield. Vegetation of leguminous green manure crops significantly enhanced the soil organic carbon, total nitrogen and the availability of nutrient essentials like phosphorus and potassium. The physical properties of the soil, especially lower bulk density, were also made, which enhanced the growth of the crops further.

The results prove that green manuring does not only enhance the health of the soil but also produces impressive crop yield and biomass. Combination of green manuring and a lower chemical fertilizer application has been found to be the most constructive treatment, which provided a balanced solution, which would yield maximum productivity and minimum environmental harm. This shows that green manuring has a promise of decreasing the use of synthetic manure without yielding back.

All in all, green manuring is a viable and sustainable method of agronomy and can be used to revive soil fertility, enhance crop production and sustain agriculture in the long run. The adoption of it can be of importance in dealing with soil degradation and food issues, especially in cereal-based agricultural systems.

Recommendations

Relying on the results of this research, one can make the following recommendations:

To begin with, it is necessary to promote the use of green manuring by the farmers, in particular the use of leguminous species as a part of the wide-ranging soil fertility management approach. The long-term benefits of green manuring should be raised through extension services and agricultural advisory programs on the long run benefits of the process of green manuring on soil health and crop productivity.

Second, green manuring is to be associated with a lower rate of the chemical fertilizers to enhance the efficiency of nutrient utilization and reduce the production cost. The integrated nutrient management strategies development should be promoted by the policy makers and agricultural institutions using means of subsidies, training, and demonstration trials.

Third, subsequent studies need to be aimed at improving the selection of green manure species, timing of biomass incorporation and compatibility of the cropping system in various agro-climatic conditions. To determine the effects of green manuring on the climate resilience and soil carbon sequestration in the long term, such studies are required.

Lastly, the use of green manuring in national soil health and sustainable agriculture initiatives by the government and research organizations must be included. Such practice should be encouraged to achieve long-term beneficial effects on the environment such as sustainable farming, minimization of chemical contamination, and enhancement of food security.

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