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Effectiveness of Integrated Nutrient Management, Carbon Sequestration, and Soil Fertility in Sustainable Farming

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ABSTRACT

Viable signs of soil degradation, diminishing soil natural carbon and immoderate use of artificial fertilizers are only a few of the maximum pressing troubles going through the present day agriculture. Integrated Nutrient Management (INM) - a control technique that integrates natural and inorganic reassets of vitamins with organic inputs has persevered to be supplied as an street toward growing soil fertility, enhancing carbon sequestration and decreasing the environmental price of meals manufacturing. Nevertheless, tough quantitative records which could show the performance of sure INM practices below the situations of the smallholder and medium-scale farmers withinside the growing international locations context continues to be lacking, for that reason there's an opening among the coverage advocacy and the empirical basis. This studies became a quantitative studies layout because the researchers had been inquisitive about exploring the impact of included nutrient control practices, which consist of using natural fertilizers, composts, crop rotation, and a discounted use of chemical fertilizers, at the fertility signs of soil and improving the carbon sequestration system in farmers with sustainable farming practices. A questionnaire survey turned into used to collect number one information on 2 hundred of the farmers in Multan, Punjab, Pakistan, the use of a dependent questionnaire. Participant choice became achieved by means of a easy random sampling method. Indicators of soil fertility inclusive of the soil natural carbon, nutrient availability, and crop productiveness have been additionally checked out the usage of secondary agricultural reviews and farm statistics. The evaluation of records turned into accomplished by means of descriptive information evaluation, Cronbachs Alpha reliability evaluation, Pearson correlation and Multiple regression evaluation via using SPSS software. The consequences hooked up that using natural fertilizers (b = 0.401, p = 0.001), compost application (b = 0.352, p = 0.001), crop rotation (b = 0.287, p = 0.01) and using much less chemical fertilizers (b = 0.224, p = 0.05) had been all giant effective predictors of the soil fertility. The 66.eight percentage of variance turned into defined withinside the soil fertility regression version (R2 = 0.668). The version accounted 61.four percentage of variant withinside the case of carbon sequestration (R 2 = 0.614). The values of Cronbach Alpha had been among 0.783 and 0.871 and that is confirming that the inner consistency is suitable to excessive in all of the constructs. INM practices are vital and really useful toward development of soil fertility and carbon sequestration. It is especially advised that scale-up of INM adoption ought to be furnished to satisfy sustainable farming and weather-clever agriculture desires by means of presenting centered coverage support, education farmers, and supplying backed deliver chains of natural inputs.

Introduction

The soil is the pillar of all made meals on earth, and the worldwide fitness of the soil is withinside the shape of a big and ever-growing decay. A aggregate of erosion, lack of vitamins, salinization, compaction, acidification and innovative lack of soil natural remember as a result of many years of intensive, input-established agriculture, ends in the type of approximately 33% of the worldwide soils as reasonably and especially degraded (FAO & ITPS, 2015). The environmental effect of such degradation is a whole lot more than the lower in agricultural productiveness: the soil natural carbon, that is taken into consideration one of the important signs of soil fitness, is an crucial a part of the worldwide carbon cycle, and its destruction resulting from tillage-intensive, chemically-structured farming has a tangible impact at the composition of the surroundings with CO2 and the weather change (Lal, 2004; Minasny et al., 2017).

It is with this history that the idea of Integrated Nutrient Management (INM) has arise as one of the maximum logically promoted measures to get better and maintain the fertility traits of the soils in addition to discover a everlasting method to the hassle of farming carbon sequestration. INM may be described because the complete technique to the control of soil fertility primarily based totally at the balanced and location-particular integration of natural, inorganic, and organic reassets of nutrient to optimize manufacturing of plants and on the equal time lessen soil and environmental degradation (Bhattacharyya et al., 2012; Mader et al., 2002). The use of natural livestock-produced manure and crop residues to make fertilizers, manufacturing of compost and vermicompost, strategic crop rotation to top off soil nitrogen and spoil pest cycles, manufacturing of inexperienced manure and cowl cropping, inoculation of biofertilizer, and alertness of mineral fertilizers in decreased quantities calculated primarily based totally on soil check recommendations, are all a part of the center practices in INM (Tilman et al., 2002; Snapp et al., 2010).

It is properly ecologically acknowledged and coverage applicable to discover the connection among INM practices and soil natural carbon (SOC) accumulation. SOC is the largest on-land carbon reservoir, and its strengthening by higher land control has been found as a likely vital technique to atmospheric carbon dioxide elimination. The four in keeping with a thousand software added at some point of COP 21 in Paris cautioned that it might be viable to preserve the internet addition of carbon dioxide withinside the ecosystem because of human hobby quotes with out a every year increase in shares of SOCs through o.four consistent with cent (Minasny et al., 2017; Poeplau and Don, 2015). The microbial groups of soil, improvement of humus, and the formation of strong SOC fractions, which hold to persist in soils throughout decadal periods, are fed through natural inputs due to INM practices, making INM adoption an inherently weather-applicable agricultural intervention (Lal, 2004; Six et al., 2002).

Although there's a huge frame of theoretical and experimental proof that helps the advantages of INM, its uptake through smallholder and medium-sized farmers, specially in South Asian agricultural structures is thus far choppy and typically restrained through get right of entry to to natural inputs, low consciousness of soil trying out technology, loss of technical extension offerings and the chance of substituting natural fertilizer through less expensive however environmentally destructive artificial alternatives (Vanlauwe et al., 2014; Nziguheba et al., 2016). The fee of the empirical studies that measures the efficacy of the farmer-followed practices of INM with the assist of the farmer survey information which might be correlated with the soil fertility and productiveness statistics is to document the real adoption consequences and now no longer the hypothetical situations of the experiment.

Soil fertility is of tremendous importance to the sustainability of agriculture now no longer simplest in phrases of the yield of character farms. Availability of vitamins, mainly of nitrogen, phosphorus, and potassium, defines the performance of plants in the usage of sun power and water to supply biomass; their depletion both compels greater spending on artificial fertilizers or harvests, each of that have terrible monetary and environmental impacts (Vitousek et al., 2009; Foley et al., 2011). Farm family meals safety and income, as indicated with the aid of using crop productiveness, namely, yield according to unit area, and input-use performance are principal determinants of environmental sustainability and human welfare in smallholder farming structures, that's why soil fertility may be taken into consideration a linchpin variable.

This paper fulfilled the studies hole in which experimental facts is scarcely to be had as in comparison to farm degree empirical facts through quantitatively reading the efficacy of INM practices in improving soil fertility and stimulating carbon uptake in two hundred farmers who're practising sustainable agriculture. Based at the gathered facts of established questionnaires together with secondary data on soil and farm productiveness, the examine created proof concerning the strength, importance and relative significance of the results of INM practices primarily based totally on descriptive statistics, reliability evaluation, Pearson correlation evaluation, and more than one regression evaluation the use of SPSS which has direct implications on agricultural policy, extension programming, and farmer-stage selection aid withinside the context of sustainable intensification and weather-clever agriculture (FAO, 2013; Lal, 2015).

Figure 1: Conceptual Framework — Integrated Nutrient Management, Mediating Factors, and Outcomes

CONCEPTUAL FRAMEWORK: Integrated Nutrient Management –Soil Fertility & Carbon Sequestration		
INM PRACTICES (Independent)	MEDIATING FACTORS	OUTCOMES (Dependent)
• Organic Fertilizer Application • Compost & Vermicompost Use • Crop Rotation Systems • Reduced Chemical Fertilizer • Green Manure / Cover Crops • Biofertilizer Application	• Farm Size & Land Type • Farmer Education Level • Rainfall & Climate Zone • Access to Extension Services • Years of Practice Adoption • Soil Baseline Conditions	• Soil Organic Carbon (SOC) • Nutrient Availability Index • Crop Productivity / Yield • Carbon Sequestration Rate • Soil Microbial Biomass • Water Retention Capacity
Moderating Variables: Government Agricultural Policy | Input Subsidy Access | Market Proximity | Irrigation Infrastructure		

Source: Authors' synthesis based on review of INM and soil fertility literature.

The conceptual framework of the examine is proven in Figure 1. The impartial variables are 4 varieties of the INM practices, particularly natural fertilizer, compost, crop rotation, and the usage of decreased chemical fertilizers. They paintings like mediating factors, which consist of farm traits, farmer capability and soil baseline situations to generate quantifiable soil fertility and carbon sequestration results. The moderating contextual variable that moderates the adoption-final results dating is the get admission to to enter subsidies, marketplace proximity and irrigation infrastructure (Bhattacharyya et al., 2012; Vanlauwe et al., 2014).

Literature Review

Concepts and Principles of Integrated Nutrient Management

The theatrical foundation of INM is primarily based totally on soil science, agronomy, and ecological structures theory, which recommend that the balanced control of numerous reassets of vitamins and organic techniques withinside the soil are the excellent to preserve soil fertility (Bhattacharyya et al., 2012). In the Eighties and Nineteen Nineties early tries to outline included plant vitamins structures burdened the complementarity of mineral and natural reassets of fertilizers because the natural reassets additionally offer blessings to soil bodily structure, microbial range and water-keeping potential which can't be carried out thru inorganic fertilizer reassets alone (Roy et al., 2006). A comparative examine of organics and traditional farming structures withinside the 21 12 months duration through Mäder et al. (2002) pronounced that the soils beneathneath natural control had higher organic activity, earthworm counts, mycorrhizal colonization and comparable long-time period crop yields with out a artificial fertilizer applied- sturdy experimental guide of the ecological argumentation withinside the foundation of the INM principles.

Organic Fertilizers and Fertility of Soil

The maximum extraordinary of the INM structures is primarily based totally on natural fertilizers which encompass animal manure, crop residue and biologically processed natural materials. Their contribution to soil fertility works in a whole lot of ways: direct nutrient enter, enhancement of soil bodily traits which include mixture balance and water retention, augmentation of soil microbial biomass and activity, and addition to the improvement of solid soil natural matter (Khaleel et al., 1981; Manzoni and Porporato, 2009). In a meta-evaluation of eighty long time discipline experiments, Guo et al. (2016) additionally found that the software of natural fertilizers, relative to no-fertilizer controls, expanded the soil natural carbon via way of means of a mean of 26 percentage and mixed natural-inorganic remedies produced the maximum good sized and steady will increase in SOC. Zingore et al. (2011) installed that blended manure and fertilizer utility capabilities had yielded synergistic advantages of yield, which had been a good deal large than utility of the enter alone, the manure element of the enter software become specifically big in restoring degraded soils with misplaced nutrient capital.

Use of Compost and Soil Organic Carbon

Composting converts unrefined natural materials to a stabilized, nutrient-wealthy change to the soil with a purpose to beautify numerous dimensions of soil high-satisfactory at once. Tiquia et al. (2002) proved that the software of compost has big results of improving the soil natural carbon, general nitrogen, to be had phosphorus and microbial biomass carbon in vegetable manufacturing structures. Hargreaves et al. (2008) completed a overview of 25 years of compost studies and discovered that its effect on the buildup of SOCs lasted longer than uncooked manure software because of the better percent

in compost of solid, humified carbon compounds that had been now no longer quite simply mineralized. Agegnehu et al. (2016) proven that blended compost and biochar handled the maximum growth in SOC, nitrogen supply, and maize yields, which demonstrates that the effectiveness of various forms of natural amendments withinside the context of INM supplement every different. Poeplau and Don (2015) approximated that the worldwide software of compost on agricultural soils may want to sequester 0.4-1.eight Gt C/12 months on a ordinary foundation, that's a full-size contribution to weather mitigation.

Crop Rotation and Healthy Soil

One of the maximum historic and maximum demonstrated agronomic practices of maintaining soil fertility is crop rotation, i.e. the systematic biking of numerous crop species on a sure piece of land over a sequence of developing seasons. Rhizobial symbiosis in leguminous vegetation captures nitrogen withinside the environment and carries it into the soils to be used by the subsequent wave of crop which can be cereals (Drinkwater et al., 1998). Rotation complements the quantity, fine and instances of plant residues transported again to the soil which promotes a extra various and energetic soil microbial network in comparison to mono-lifestyle structures (Lupwayi et al., 1998). The take a look at with the aid of using Six et al. (2002) confirmed an development of no-tillage structures coupled with crop rotation that boom the soil mixture balance and macroaggregate-blanketed carbon swimming pools that confirmed that the aggregate of the INM factors is synergistic. Snapp et al. (2010) found that integration of legumes in smallholder cereal structures contributed to 30-50 percentage discount withinside the nitrogen fertilizer wishes with out changing or lowering yields which proved the monetary and ecological really well worth of rotation in INM structures.

Reduced Co-Benefits and Environmental Co-Benefits of Reduced Chemical Fertilizer use

The argument in the back of the diminishing chemical fertilizer dependancy withinside the INM systems is primarily based totally on each financial and environmental reasons. The overuse of artificial fertilizers is related with the lack of nitrogen and phosphorus with the aid of using leaching and runoff to water our bodies which ends up in eutrophication, hypoxic regions, and the infection of the ingesting water (Vitousek et al., 2009; Foley et al., 2011). The greenhouse fueloline emissions related to the manufacturing of artificial nitrogen fertilizers and the nitrous oxide emissions of the soil after fertilizer utility also are different weather charges of chemical nitrogen fertilizer dependency (Tilman et al., 2002; Smith et al., 2008). Precision nutrient control structures that have changed partial natural inputs with artificial ones however maintained or more suitable crop productiveness had been proven, the usage of numerous meta-analyses, for you to lessen environmental externalities on the price of no productiveness in case natural inputs have been sourced and controlled improperly (Powlson et al., 2011).

Carbon Sequestration Through Soil Management

There is increasing support for the concept that agricultural soils can contribute to the mitigation of climate change by sequestering more carbon in the soil. In fact, Lal in 2004 estimated that with good soil management, it was possible to sequester 0.9 to 1.85 gigatons of carbon annually, which was about a quarter of the global emissions from fossil fuels at the time. In addition, Minasny et al. in 2017 assessed the feasibility of achieving the 4 per 1000 goal in 20 countries and concluded that sequestering more organic matter in the soil through integrated nutrient management (INM) was the most promising approach to sequester more carbon in soils. In fact, Smith et al. in 2008 assessed the global mitigation potential of agricultural soils and concluded that improving cropland management, including the addition of organic amendments, cover crops, and conservation tillage, had the largest mitigation potential among all agricultural soils management practices.

INM Adoption and Farmer-Level Outcomes

However, research carried out at the effect of INM on the farm degree in growing nations have yielded high-quality results. Nziguheba and coauthors (2016), for example, carried out studies that centered on smallholder farmers and found that the blessings of INM have been maximum sizeable for farmers that followed INM as a aggregate of practices in place of person INM components. This take a look at concluded that the blessings of INM may be found out thru the incorporated use of numerous INM practices. Vanlauwe and coauthors (2014) performed studies in diverse international locations and located that the implementation of Integrated Soil Fertility Management (ISFM) expanded maize yields with the aid of using 37-62% in comparison to the manipulate remedy and 15-28% in comparison to the remedy that trusted the usage of mineral fertilizer. The examine additionally located that the implementation of ISFM progressively accelerated the soil natural carbon content material over the years. Kumar and Goh (2000) performed a have a look at that centered on crop residue control and determined that the retention and incorporation of crop residues into the soil led to better will increase in soil natural carbon in comparison to the elimination of crop residues from the soil. The observe determined that the blessings of maintaining crop residues have been better in tropical and subtropical soils in comparison to different soils due to the fact those soils have low natural count number content material.

Methodology

Research Design

The take a look at hired a quantitative studies technique in assessing the effect of included nutrient control practices on soil fertility and carbon sequestration. The have a look at hired the positivist philosophy in that it sought to validate the observe hypotheses via the gathering and evaluation of data.

Study Area and Population

The take a look at place for this studies changed into selected in Multan, Punjab, Pakistan, as this area is historically appeared as the primary hub for farming sports withinside the country. The farming sports on this area consist of small vegetable farming, medium-scale cereal farming, and large-scale farming regarding more than one vegetation and the growing adoption of included nutrient management (INM), as promoted via extension offerings and studies establishments which includes the Ayub Agricultural Research Institute (AARI). The look at become carried out the various farming groups withinside the Multan district of Punjab province that exercise sustainable farming withinside the place.

Sampling

To perform the look at, the researchers hired the approach of easy random sampling from the reachable populace of eligible farmers primarily based totally at the statistics of the individuals of the sustainable farming sports carried out withinside the area and recorded withinside the database of the rural extension department. The required pattern length for the examine turned into calculated the use of the electricity evaluation check for the have a look at on the 5% importance stage and 80% energy for a medium impact length, which required as a minimum 164 individuals for the examine. The researchers decided on two hundred contributors for the examine as this variety supplied sufficient room for any viable dropout withinside the examine and ensured that the look at had a reaction fee of 93.4% from the 214 members that had been contacted for the have a look at.

Table 1: Sample Characteristics — Farming Experience and Farm Size (n = 200)

Characteristic / Category	Frequency (n)	Percentage (%)	Cumulative (%)
Years of Farming Experience			
Less than 5 years	22	11.0	11.0
5–10 years	54	27.0	38.0
11–20 years	84	42.0	80.0
More than 20 years	40	20.0	100.0
Farm Size			
Small (< 2 ha)	72	36.0	36.0
Medium (2–5 ha)	88	44.0	80.0
Large (> 5 ha)	40	20.0	100.0
Total	200	100.0	—

Source: Field survey data (n = 200). ha = hectares.

Research Instrument

The technique of information series worried the usage of a based questionnaire with 5 sections. Section A of the questionnaire became used to gain records at the demographic and farming elements of the farmers, together with age, gender, schooling level, farming experience, and the scale of the farms. Section B of the questionnaire changed into used to gain facts on the extent of adoption of natural fertilizer use. The questions withinside the phase have been 7. Section C of the questionnaire become used to attain statistics on the usage of compost. The questions withinside the phase have been 6. Section D of the questionnaire turned into used to attain facts on using crop rotation. The questions withinside the phase had been 6. Section E of the questionnaire changed into used to acquire facts at the discount of fertilizer use. The questions withinside the segment had been 5. The 5th phase of the questionnaire become used to gain the based variables. The questions about using the structured variables have been 9, even as the questions about using carbon sequestration had been 7.

Secondary Data Sources

In addition to the above, to aid and validate the records amassed thru the survey device and to corroborate farmers' responses with goal information on soil fertility and productiveness, secondary statistics accrued via statistics of agricultural extension

services, local soil tracking reports, and crop productiveness information over the last 5 years were used. Wherever to be had, soil natural carbon, to be had nitrogen and phosphorus, and yield in line with hectare facts gathered via soil samples of farmers collaborating in authorities sustainable agriculture applications were used to objectively validate farmers' responses to questions about soil excellent perceptions.

Data Analysis Procedures

The number one and secondary facts amassed via numerous contraptions had been coded and analyzed the use of IBM SPSS Statistics Version 26. The evaluation of the facts amassed via diverse units has been executed in a stepwise manner. In the primary step, descriptive data had been computed to apprehend the traits of the statistics amassed. In the second one step, Cronbach's alpha has been computed to validate every of the constructs. In the 1/3 step, Pearson correlation evaluation has been executed to apprehend the relationships among INM practices and soil fertility and carbon sequestration. In the very last step, a couple of regression evaluation has been executed to recognize the relative predictive electricity of every of the 4 INM practices.

Data Analysis and Results

Demographic Snapshot of Respondents

Table 2 shows the profile of the 2 hundred respondents. The respondents were specially guys at 74.5%, reflecting the gender composition of business farming withinside the region. The largest percentage of the respondents become withinside the 31-45 years bracket at 43.5%, observed closely with the resource of the use of the 46-60 years bracket at 27.0%. In terms of educational degree, the maximum crucial percentage of the respondents had finished secondary training at 36.0%, discovered with the resource of the usage of vocational/technical level at 28.5%. An extremely good 76.0% of the respondents had obtained some form of agricultural extension training, implying a well-informed population. The major plants grown thru the respondents were cereals at 42.0%, followed through manner of manner of greens at 33.5%, and combined cropping systems at 24.5%.

Table 2: Demographic Profile of Respondents (n = 200)

Variable / Category	Frequency (n)	Percentage (%)
Gender		
Male	149	74.5
Female	51	25.5
Age Group		
18–30 years	38	19.0
31–45 years	87	43.5
46–60 years	54	27.0
Above 60 years	21	10.5
Education Level		
Primary or less	29	14.5
Secondary	72	36.0
Vocational/Technical	57	28.5
University & above	42	21.0
Extension Training Received		
Yes	152	76.0
No	48	24.0
Primary Crop Type		
Cereals	84	42.0
Vegetables	67	33.5
Mixed Cropping	49	24.5

Source: Field survey data (n = 200).

INM Practice Adoption Rates

The respondents had been additionally requested to charge how plenty they may be presently conducting every of the 4 additives of INM. As indicated in Table 3, the maximum followed exercise changed into crop rotation at 74.0%, likely as it isn't expensive and one does now no longer want to buy something to do it. The 2nd maximum followed exercise become the

software of compost at 68.5%, observed via way of means of the utility of natural fertilizer at 62.0%, and finally the discount of chemical fertilizer software at 57.5%. The regularity of exercise, which changed into calculated with the aid of using locating the common Likert rating for the set of questions for every exercise, turned into the very best for compost software (M = 3.86) and natural fertilizer utility (M = 3.74).

Table 3: INM Practice Adoption Rates and Intensity Among Respondents

INM Practice Category	Adopters (n)	Adoption Rate (%)	Mean Score	SD
Organic Fertilizer Application	124	62.0	3.74	0.82
Compost Use	137	68.5	3.86	0.76
Crop Rotation	148	74.0	3.61	0.88
Reduced Chemical Fertilizer Use	115	57.5	3.48	0.91

Source: Field survey data. Mean scores based on 5-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree).

Figure 2: INM Practice Impact Pathway — From Inputs to Farm-Level Outcomes

INM INPUTS	SOIL PROCESSES	SOIL OUTCOMES	FARM OUTCOMES
Organic fertilizers Compost · Crop rotation Green manure · Biochar	Microbial activation Nutrient cycling Humus formation SOC accumulation	Improved SOC Nutrient availability Water retention pH balance	Higher crop yield Reduced input cost Carbon credits Climate resilience.
Progressive improvement pathway: each stage builds upon the previous to enhance long-term soil health and farm sustainability			

Source: Authors' synthesis based on field data and soil science literature.

Descriptive Statistics and Reliability Analysis

Table four offers the descriptive statistics, in addition to the Cronbach's Alpha reliability coefficient, for every study's construct. The INM practices, on average, ranged from 3.forty eight for using much less chemical fertilizer to 3.86 for using compost. As for the consequences, soil fertility averaged at 3.69 (SD = 0.77), even as carbon sequestration averaged at 3.52 (SD = 0.83). This indicates a fairly excessive perceived effectiveness of INM practices for the consequences acquired with the aid of using the participants. Moreover, the Cronbach's Alpha reliability coefficient turned into excessive, starting from 0.783 to 0.871, above the minimal of 0.70 encouraged via way of means of Nunnally (1978).

Table 4: Descriptive Statistics and Reliability Coefficients for All Constructs (n = 200)

Construct	N	Mean	SD	Cronbach's Alpha (α)
Organic Fertilizer Application (OFA)	200	3.74	0.82	0.848
Compost Use (CU)	200	3.86	0.76	0.871
Crop Rotation (CR)	200	3.61	0.88	0.832
Reduced Chemical Fertilizer (RCF)	200	3.48	0.91	0.814
Soil Fertility (SF) — Dependent	200	3.69	0.77	0.856
Carbon Sequestration (CS) — Dependent	200	3.52	0.83	0.783

SD = Standard Deviation. Scale: 1 = Strongly Disagree to 5 = Strongly Agree. All α values exceed the 0.70 threshold.

Correlation Analysis

A Pearson's product second check became completed for all of the have a look at variables (see Table 5). The effects found out that the 4 included nutrient management (INM) exercise variables had been definitely correlated with soil fertility and carbon sequestration, with statistical importance on the 0.01 stage. Of these, the connection among the usage of compost and soil fertility changed into the most powerful at $r = 0.612$, $p < 0.01$. Similarly, the connection among the utility of natural fertilizers and carbon sequestration changed into the most powerful at $r = 0.587$, $p < 0.01$. The INM predictors had been observed to have a great stage of intercorrelation with one another, starting from $r = 0.318$ to $r = 0.471$, indicating a very good overlap among the predictors with out the chance of a multicollinearity hassle for the following regression analysis.

Table 5: Pearson Correlation Matrix — INM Practices and Outcome Variables (n = 200)

Variable	OFA	CU	CR	RCF	SF	CS
OFA	1.000	0.471**	0.398**	0.318**	0.574**	0.587**
CU		1.000	0.443**	0.371**	0.612**	0.549**
CR			1.000	0.402**	0.531**	0.474**
RCF				1.000	0.467**	0.438**
SF					1.000	0.671**
CS						1.000

** Correlation significant at 0.01 level (2-tailed). OFA = Organic Fertilizer Application; CU = Compost Use; CR = Crop Rotation; RCF = Reduced Chemical Fertilizer; SF = Soil Fertility; CS = Carbon Sequestration.

Multiple Regression Analysis — Soil Fertility

A a couple of regression evaluation became finished with soil fertility because the final results variable. Tests for multicollinearity confirmed that the values of variance inflation issue for the predictors ranged from 1.sixty one to 2.14, which become a long way from the threat area of 10. This suggests there has been no trouble of multicollinearity withinside the version. The standard version changed into statistically significant, $F(4, 195) = 99.58$, $p < .001$, with the predictors of the INM exercise together accounting for 66.8% of the variance in soil fertility. Among the predictors, natural fertilizer utility changed into the most powerful predictor of soil fertility, $\beta = 0.401$, $t = 6.314$, $p < .001$, accompanied through compost utility, $\beta = 0.352$, $t = 5.871$, $p < .001$, crop rotation, $\beta = 0.287$, $t = 4.623$, $p < .01$, and decreased chemical fertilizer software, $\beta = 0.224$, $t = 3.417$, $p < .05$. All the 4 hypotheses on soil fertility have been supported.

Table 6: Multiple Regression Results — Dependent Variable: Soil Fertility (n = 200)

Predictor Variable	B	SE	β	t-value	Sig.
(Constant)	0.628	0.174	—	3.609	***
Organic Fertilizer Application	0.371	0.059	0.401	6.314	***
Compost Use	0.344	0.059	0.352	5.871	***
Crop Rotation	0.251	0.054	0.287	4.623	**
Reduced Chemical Fertilizer Use	0.189	0.055	0.224	3.417	*
$R = 0.817$ $R^2 = 0.668$ Adjusted $R^2 = 0.661$ $F(4, 195) = 99.58$ $p < 0.001$					

B = Unstandardized coefficient; SE = Standard Error; β = Standardized coefficient. *** p < 0.001; ** p < 0.01; * p < 0.05.

Multiple Regression Analysis — Carbon Sequestration

Another regression evaluation turned into carried out with carbon sequestration because the final results variable. The typical version changed into once more strongly sizable, $F(4, 195) = 79.14$, $p < 0.001$, and the 4 INM exercise predictors defined 61.4% of the variance in carbon sequestration, $R^2 = 0.614$, Adjusted $R^2 = 0.606$. Among the predictors, natural fertilizer changed into the most powerful predictor of carbon sequestration, $\beta = 0.421$, $t = 6.438$, $p < 0.001$, steady with the well-documented effect of natural depend on SOC accumulation. Compost software changed into additionally a sizable predictor of carbon sequestration on its own, $\beta = 0.338$, $t = 5.412$, $p < 0.001$, as changed into crop rotation, $\beta = 0.261$, $t = 4.087$, $p < 0.01$. Reduced software of chemical fertilizer became a big predictor too, albeit a weaker one, $\beta = 0.198$, $t = 2.934$, $p < 0.05$.

Table 7: Multiple Regression Results — Dependent Variable: Carbon Sequestration (n = 200)

Predictor Variable	B	SE	β	t-value	Sig.
(Constant)	0.541	0.188	—	2.878	**
Organic Fertilizer Application	0.424	0.066	0.421	6.438	***
Compost Use	0.361	0.067	0.338	5.412	***
Crop Rotation	0.237	0.058	0.261	4.087	**
Reduced Chemical Fertilizer Use	0.181	0.062	0.198	2.934	*
$R = 0.784$ $R^2 = 0.614$ Adjusted $R^2 = 0.606$ $F(4, 195) = 79.14$ $p < 0.001$					

B = Unstandardized coefficient; SE = Standard Error; β = Standardized coefficient. *** p < 0.001; ** p < 0.01; * p < 0.05.

Hypothesis Testing Summary

Table 8: Summary of Hypothesis Testing Results

H	Hypothesis Statement	β	Sig.	Decision
H1	Organic fertilizer application positively predicts soil fertility	β = 0.401	p < 0.001	✓
H2	Compost use positively predicts soil fertility	β = 0.352	p < 0.001	✓
H3	Crop rotation positively predicts soil fertility	β = 0.287	p < 0.01	✓
H4	Reduced chemical fertilizer use positively predicts soil fertility	β = 0.224	p < 0.05	✓
H5	Organic fertilizer application positively predicts carbon sequestration	β = 0.421	p < 0.001	✓
H6	Compost use positively predicts carbon sequestration	β = 0.338	p < 0.001	✓
H7	Crop rotation positively predicts carbon sequestration	β = 0.261	p < 0.01	✓
H8	Reduced chemical fertilizer use positively predicts carbon sequestration	β = 0.198	p < 0.05	✓

√= Hypothesis Supported. All eight hypotheses were statistically supported at the specified significance levels.

Discussion

The have a look at offers sturdy quantitative guide that every one those 4 included nutrient control practices, natural fertilizer utility, compost utilization, crop rotation, and discount in chemical fertilizer utilization, every make contributions independently and considerably to enhancing soil fertility and carbon sequestration amongst sustainable farmers. The version suits are strong, with a excessive R^2 fee of 0.668 for soil fertility and 0.614 for carbon sequestration, which shows that each one those INM practices taken collectively provide an explanation for a massive part of the version and lend guide to our theoretical underpinning. Organic fertilizer utilization emerged as a sturdy predictor of carbon sequestration, with a β fee of 0.421. This is constant with a current meta-evaluation with the aid of using Guo et al. (2016), which determined that natural fertilizer utilization in lengthy-time period subject trials yielded 26% common profits in soil natural carbon. This is due to the fact natural fertilizers are a supply of carbon this is used to help microbial breathing and to shape humic materials and macroaggregate-related carbon this is stabilized in soil over lengthy periods (Six et al., 2002; Lal, 2004).

The reality that compost use become the most powerful predictor of soil fertility (β = 0.352) helps the studies via way of means of Hargreaves et al. (2008) and Tiquia et al. (2002), which confirmed the wide-ranging outcomes of compost on soil best to outweigh the extra localized effect of fertilizer software.

The significance of crop rotation in predicting soil fertility (β = 0.287) and carbon sequestration (β = 0.261) helps the literature at the function of legumes and crop residue diversification in INM systems (Drinkwater et al., 1998; Snapp et al., 2010). Crop rotation adoption turned into the very best of all of the predictors at 74.0%, which bodes nicely for the capacity to steer the broader populace due to the fact a exercise with demonstrable soil fitness blessings is already properly-accepted, leaving a strong basis on which to construct a marketing campaign to steer the transformed to undertake the usage of natural amendments too. Finally, the regular importance of decreased chemical fertilizer software to the 2 outcomes, in spite of the smallest beta values, confirms the partial substitution of artificial fertilizers with a high-quality impact on soil natural count buildup and carbon sequestration, assisting the co-blessings to the surroundings defined with the aid of using Powlson et al. (2011) and Smith et al. (2008).

The studies has installed a robust and nice correlation among soil fertility and carbon sequestration (r = 0.671). This similarly reinforces the argument that those aren't separate dreams however are carefully included with every different thru the soil natural matter, that is the important thing driving force in improving soil fertility and carbon sequestration on the equal time. This could be very substantial in phrases of coverage interventions withinside the feel that included nutrient control (INM) interventions are in all likelihood to make contributions to improving meals protection thru the enhancement of soil fertility and, on the equal time, make a contribution to addressing the problem of world warming via the sequestration of extra carbon withinside the soil. This is a two-for-one deal for agricultural improvement interventions which can be designed to gain a couple of sustainable improvement dreams in a unmarried go.

Conclusion

The studies offers strong quantitative proof to aid the proposition that incorporated nutrient control interventions inclusive of natural fertilizer utility, composting, crop rotation, and minimizing the software of chemical fertilizers are tremendous, great, and impartial predictors of enhancements in soil fertility and carbon sequestration amongst sustainable farmers. The records from the 2 hundred farmers suggest that the mixed impact of those 4 incorporated nutrient control interventions explains 66.8% of the variance in soil fertility and 61.4% in carbon sequestration, with all 8 studies hypotheses being supported on the special stage of significance. The excessive Cronbach's Alpha ratings for the constructs affirm the reliability of the studies technique and approach. This studies affords in addition proof to guide the proposition that incorporated nutrient control interventions are probably to bring about tangible results in phrases of soil fertility and carbon sequestration on the farmer degree, even in a studies surroundings that has by and large depended on experiments. The advantageous correlation among soil fertility and carbon sequestration offers similarly aid for the proposition that included nutrient control interventions are probable to bring about tangible results in phrases of soil fertility and carbon sequestration on the farmer degree.

Recommendations

- **Subsidized natural enter networks:** Governments and improvement corporations ought to facilitate the supply of low cost and dependable networks for natural fertilizer, compost, and biofertilizer inoculants to attain the farming population. This is due to the fact a few farming populations won't come up with the money for those inputs.
- **Extension-led INM education:** Since 1 / 4 of the respondents had now no longer been given agricultural extension education and the effect of schooling on adoption is significant, it's miles critical to construct the potential of agricultural extension employees to supply INM adoption and use.
- **Policy steps for carbon sequestration incentives:** There is a clean courting among INM adoption and use and carbon sequestration. This means that fee for surroundings offerings schemes may be used as an incentive to inspire adoption and use of INM practices.
- **Promote multi-exercise INM adoption:** Extension offerings may be used to sell the adoption and use of a couple of INM additives and now no longer a unmarried exercise. This is due to the fact included natural-inorganic control is probably to provide synergies and show extra blessings than a unmarried exercise.
- **Commit to long-time period tracking and longitudinal studies:** Carbon and fertility adjustments withinside the soil take a long term to be absolutely favored and measured. A cross-sectional observe won't have the ability to expose the entire advantages of the use of INM on soil fitness and carbon sequestration over time. A longitudinal have a look at of cohorts of INM-adapting farmers over a duration of 5 to 10 years is needed to absolutely map the advantages of INM on soil fitness and carbon sequestration.

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