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The Significance of Bean Plants (Peas, Sebarga, Indigo) In Improving the Agroecological Properties of Degraded Soils

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Abstract: Soil degradation remains a major threat to farming, especially in tropical regions where organic matter is low and soils are compacted. This study examined the ability of three leguminous bean species—pea (Pisum sativum), sebarga (Lablab purpureus), and indigo (Indigofera tinctoria)—to restore key soil properties over two growing cycles. A field experiment compared these three treatments against bare fallow. The results showed that all three beans improved soil health, but in different ways. Indigo gave the highest increase in soil organic carbon and microbial activity, sebarga was best at breaking up compacted subsoil, and pea released nitrogen most quickly for the following crop. We conclude that using these beans, especially in combination, offers a practical, low-cost method to regenerate degraded soils.

Keywords: Legumes, soil regeneration, green manure, nitrogen fixation, soil structure.

Introduction: Degraded soils are now a common problem across many agricultural regions. When soil loses its organic matter, becomes compacted, and shows low nutrient levels, crop yields fall sharply, and farmers often respond by using more synthetic fertilizers. However, this approach does not fix the underlying physical and biological damage [7, 401-408]. For this reason, researchers have turned to cover crops, particularly legumes, as a more sustainable solution. Legumes have the unique ability to fix atmospheric nitrogen through symbiosis with rhizobia bacteria, and they produce large amounts of biomass that can be returned to the soil [5]. Nevertheless, most studies have focused on common legumes such as clover or alfalfa, while other bean species that are locally available and culturally important remain understudied. Specifically, three beans—pea (Pisum sativum), sebarga (Lablab purpureus, also known as hyacinth bean), and indigo (Indigofera tinctoria)—are often grown in smallholder systems but have not been systematically compared for their soil restoration potential [1]. Therefore, the objective of this study was to quantify how each of these three species affects the physical, chemical, and biological properties of a moderately degraded soil. We hypothesized that all three would improve soil health relative to fallow land, but that indigo, being a perennial woody legume, would have the strongest effect on long-term carbon storage, whereas sebarga, with its deep taproot, would best relieve subsurface compaction.

METHODS

The experiment was carried out on a degraded agricultural site with a history of continuous maize cultivation and no organic amendments for at least five years. The soil was classified as a Ferralsol with a sandy clay loam texture. Before starting the experiment, we measured the initial soil properties in the top twenty centimeters. The soil was compacted, with a bulk density of 1.58 grams per cubic centimeter, and it contained very little organic carbon (only 0.6 percent) and total nitrogen (0.04 percent). The pH was acidic at 5.1, and the cation exchange capacity was low. We used a randomized complete block design with four treatments and four replications, giving a total of sixteen plots. Each plot measured five meters by four meters. The four treatments were: bare fallow as a control (kept weed-free by hand weeding), pea (the cool-season annual Pisum sativum variety 'Arkel'), sebarga (the warm-season annual Lablab purpureus), and indigo (the perennial shrub Indigofera tinctoria). Before sowing, all seeds were inoculated with the appropriate rhizobia strains to ensure effective nitrogen fixation. Pea was sown in early winter, while sebarga and indigo were sown in early summer of the following cycle to fit their growing seasons. No fertilizers, manure, or irrigation water were applied at any time. When each crop reached about eighty percent flowering, we cut the above-ground biomass, chopped it into small pieces, and incorporated it into the top fifteen centimeters of soil by hand hoeing. For indigo, we allowed the plants to regrow after the first cut and harvested a second biomass crop before the end of the experiment.

Soil sampling was done at three key times: before the experiment started, at ninety days after sowing (before biomass incorporation), and again thirty days after incorporating the biomass. At each sampling, we took soil from two depths: zero to twenty centimeters and twenty to forty centimeters. For physical properties, we measured bulk density using a metal cylinder of known volume, and we assessed aggregate stability by wet-sieving. For chemical properties, we analyzed soil organic carbon by the Walkley-Black method, total nitrogen by the Kjeldahl method, available nitrogen by alkaline permanganate extraction, and soil pH in a water suspension. For biological properties, we measured microbial biomass carbon using the chloroform fumigation-extraction method, and we counted earthworms by hand-sorting soil blocks of twenty-five by twenty-five by twenty centimeters. In addition, we studied root architecture at sixty days after sowing by taking soil cores of five centimeters diameter down to one meter depth, washing out the roots, and measuring root length density. All measurements were made in four replicate plots per treatment. We analyzed the data using analysis of variance, and when the overall test was significant, we compared means using Tukey's test at a probability level of 0.05. Results are presented as averages with standard deviations.

RESULTS

The results showed clear differences among the three bean species in how they improved the degraded soil. To begin with physical properties, all three legumes significantly reduced soil bulk density in the surface layer compared to the bare fallow control. However, the most striking effect was seen with sebarga in the deeper layer. At twenty to forty centimeters depth, sebarga reduced bulk density from an initial value of 1.58 down to 1.32 grams per cubic centimeter, which was a much larger change than that produced by either pea or indigo. This difference corresponded directly to the root measurements: sebarga had a root length density of 3.8 centimeters per cubic centimeter in the forty to sixty centimeter zone, while pea roots rarely went deeper than fifty-five centimeters. Turning to aggregate stability, indigo gave the best performance. The mean weight diameter of water-stable aggregates under indigo reached 0.62 millimeters, compared to only 0.29 millimeters in the control plots. In other words, indigo more than doubled the soil's resistance to water erosion.

Regarding chemical properties, all three legumes increased soil organic carbon, but indigo did so most strongly. After two cropping cycles, indigo plots contained 1.08 percent organic carbon, which was a seventy-seven percent increase above the starting value of 0.61 percent. Sebarga and pea also raised organic carbon, to 0.85 and 0.78 percent respectively, but these values were significantly lower than indigo's. For available nitrogen, the pattern was different. Pea showed the fastest release: at ninety days after sowing, before biomass incorporation, the available nitrogen in pea plots was thirty-four percent higher than in sebarga plots and twenty-eight percent higher than in indigo plots. Nevertheless, by the final sampling after biomass incorporation, the differences among the three legumes had become smaller, as all of them had added nitrogen-rich residues to the soil. In addition, soil pH rose under indigo from 5.1 to 5.7, which is a meaningful improvement for acid-degraded soils.

The biological properties followed a similar ranking. Microbial biomass carbon, which indicates the size of the active soil microbial community, was highest under indigo (342 micrograms of carbon per gram of soil), followed by sebarga (298), then pea (245), and finally the control (only 89). Earthworm populations also increased dramatically. In the control plots, we found only four earthworms per square meter. In pea plots, the number rose to eighteen, in sebarga plots to twenty-seven, and in indigo plots to thirty-five per square meter. The increase under indigo was strongly correlated with the presence of surface mulch, which remained partially undecomposed and provided shelter and food for earthworms.

In summary, the results supported our initial hypothesis: all three beans improved soil properties, but through different mechanisms. Pea acted quickly on nitrogen availability, sebarga excelled at deep soil loosening, and indigo was the best overall builder of organic carbon and biological activity.

DISCUSSION

The findings from this experiment confirm that bean plants are highly significant for improving the agroecological properties of degraded soils. However, the results also show that each species contributes in a distinct way, which has practical implications for farmers and land managers.

First, consider sebarga. Its ability to penetrate compacted subsoil down to 110 centimeters is remarkable for an annual legume. By reducing bulk density in the twenty to forty centimeter layer from 1.58 to 1.32 grams per cubic centimeter, sebarga effectively performed mechanical decompaction without any machinery. This is especially valuable in degraded soils that have developed a hard plough pan. The biopores created by sebarga roots remain open after the roots decay, allowing water to infiltrate more easily and enabling the roots of subsequent cash crops to reach deeper moisture and nutrients. Therefore, sebarga should be considered a biological subsoiler.

Next, pea offers a complementary benefit. Because pea residues have a relatively low carbon-to nitrogen ratio (approximately twelve to one), they decompose rapidly and release nitrogen in a form that plants can use right away. This explains why we measured a thirty four percent increase in available nitrogen at ninety days after sowing [2, 57-66]. For farmers who need a quick fertility boost before planting a cereal crop, pea is an excellent choice. However, pea's shallow root system limits its ability to remediate deeper soil layers, so it should not be used alone when compaction is severe.

Then, indigo stands out as a long term carbon builder. The absolute increase in soil organic carbon of 0.8 percent over two cycles is large. To put this in perspective, that increase corresponds to roughly fifteen metric tons of carbon per hectare stored in the soil. Two main reasons explain indigo's superior performance. First, indigo stems contain high levels of lignin, a complex compound that resists rapid decomposition, so carbon stays in the soil longer [4, 1650-1659]. Second, as a perennial, indigo regrows after cutting, allowing two or more biomass incorporations per year without replanting. Additionally, indigo's fibrous root system releases organic compounds into the rhizosphere, feeding soil microbes that produce sticky substances that glue soil particles together. The rise in microbial biomass carbon by 253 micrograms per gram above the control value is direct evidence of this microbial activation. Moreover, the large earthworm population under indigo (thirty five per square meter) further enhances soil porosity, nutrient cycling, and the formation of stable aggregates. In other words, indigo not only adds carbon but also creates the biological conditions for that carbon to be protected within soil aggregates.

A comparison with existing literature supports these findings. Other studies have reported that deep rooted tropical legumes can reduce bulk density, but the magnitude of reduction we observed with sebarga (0.26 grams per cubic centimeter) is larger than typical values for cowpea, probably because sebarga has a thicker and more vigorous taproot. Similarly, indigo's carbon accumulation rate matches that of well known tropical cover crops like kudzu, but indigo has the extra advantage that it produces indigo dye, a potential source of income for farmers [1]. Thus, indigo offers both ecological and economic benefits.

Nevertheless, this study has limitations. We conducted the experiment for only two cropping cycles on one soil type. Longer term studies, lasting three years or more, are needed to see whether the carbon gains under indigo are maintained or eventually saturate. Also, while we measured many soil properties, we did not quantify specific biological mechanisms such as glomalin production (a glue like protein from fungi) or the gene expression of nitrogenase in root nodules. Future research should address these deeper mechanisms. In addition, we tested each bean alone, but a logical next step is to examine mixtures or sequences, for example planting pea after sebarga or intercropping indigo with pea. Such combinations could capture the rapid nitrogen release of pea and the deep rooting of sebarga together.

For practical applications, farmers and extension agents can use the following guidelines. If the goal is to obtain a quick nitrogen supply within one to three months, incorporate pea as a short season green manure [3, 23-28]. If the main problem is a compacted subsoil, plant sebarga and allow it to grow for eighty days before chopping; this single season of sebarga will create biopores that improve the soil for years. If the aim is long term carbon sequestration and overall biological restoration, establish indigo as a perennial hedge or a managed fallow, cutting it twice each year and leaving the biomass on the surface as mulch. Furthermore, a sequential strategy—first sebarga to break the hard layer, followed by indigo to build carbon—might provide the fastest and most complete restoration of degraded soils.

CONCLUSION

In conclusion, this study demonstrates that pea, sebarga, and indigo each play a significant but different role in improving the agroecological properties of degraded soils. Pea delivers rapid available nitrogen, sebarga relieves deep soil compaction, and indigo builds soil organic carbon and biological life. Therefore, the strategic inclusion of these bean species offers a low-cost, technology light, and effective pathway for smallholder farmers to restore soil health without heavy reliance on synthetic inputs.

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