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Effect of Rhizomax on pH and Nitrogen Content of Ultisol soil in the Cultivation of White and Red turi (*Sesbania grandiflora*)

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ABSTRACT

Ultisol soil covers a very large area in Indonesia and has strong potential for farming and livestock development. However, this soil is naturally acidic, contains a lot of aluminum, and is low in nutrients and organic matter, so it needs proper management before it can be used effectively. One low-cost and environmentally friendly way to fix these problems is by applying a biofertilizer containing Plant Growth Promoting Rhizobacteria (PGPR). This study aimed to find out whether Rhizomax, a PGPR-based biofertilizer, could raise the soil pH and nitrogen content of ultisol soil when used to grow white and red turi (Sesbania grandiflora), a legume tree. The study used a Completely Randomized Design (CRD) with five treatments, namely 0, 100, 200, 300, and 400 ml of Rhizomax per plant, each repeated five times, giving 25 experimental units in total. The results showed that applying Rhizomax increased both the soil pH and the nitrogen content, with the best results found at the highest dose of 400 ml per plant.

Keywords: *Rhizomax, PGPR, ultisol soil, soil pH, nitrogen, Sesbania grandiflora*

1. Introduction

Ultisol soil has great potential for agricultural and livestock development in Indonesia, covering roughly 45.8 million hectares, or about 25% of the country's total land area [1]. Even though this makes it attractive for expanding farmland, ultisol soil needs careful management because it is naturally acidic, has high aluminum saturation, contains few nutrients and little organic matter, and is prone to erosion [2]. Acidic soil is not efficient for growing crops, so bringing the pH closer to neutral is important, since soil pH strongly affects how well plants can be cultivated.

One way to add organic matter and support life in the root zone (rhizosphere) is by planting legumes. Because legumes offer many benefits, they are widely recommended for intercropping with other plants, since they can supply nutrients to the soil and to nearby crops. As organic matter increases, soil pH tends to rise, and the growth of soil microorganisms increases as well. A higher soil pH, in turn, makes crop cultivation more efficient. The number of beneficial microorganisms in the soil can be increased by using a biofertilizer, or PGPR. Using a biofertilizer is a practical solution because it can lower production costs while being safe for the environment, which also helps reduce the need for chemical fertilizers such as urea.

Turi is a legume tree with fairly good nutritional value as animal feed. According to [3], turi is a valuable legume tree because almost every part of the plant can be used as livestock feed. Besides being used as feed, red turi can also serve as a source of biofertilizer through the inoculant found in its root nodules, which can later be reused as fertilizer for other plants. The bacteria living in symbiosis inside these root nodules help fix nitrogen from the air into the soil and improve the fertility of agricultural land [4].

To improve legume cultivation on ultisol soil and raise its pH, PGPR can be used. PGPR is an agricultural product that supports plant growth and colonizes plant roots. Rhizomax is a PGPR-based product containing bacteria such as Rhizobium sp.,

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Bacillus polymyxa, and Pseudomonas. Plant Growth Promoting Rhizobacteria (PGPR) are microbes living in the rhizosphere that can boost plant growth through several mechanisms, including nitrogen fixation, phosphate solubilization, production of plant hormones, and biological control of pathogens (Figure 1). Applying PGPR to turi plants is expected to raise soil pH, thereby improving the efficiency of cultivating crops on ultisol soil.



Figure 1. Rhizomax

2. Methodology

This study used an experimental method with a Completely Randomized Design (CRD), consisting of 5 treatments and 5 replications, giving 25 experimental units in total. The Rhizomax dosage treatments used in this study were as follows:

P0 = No Rhizomax (control)

P1 = 100 ml of Rhizomax per plant

P2 = 200 ml of Rhizomax per plant

P3 = 300 ml of Rhizomax per plant

P4 = 400 ml of Rhizomax per plant

The mathematical model of the Completely Randomized Design (CRD) used in this study follows [12].

Research Procedure

The research procedure covered several stages: preparing the growing medium, selecting seeds, soaking the seeds, sowing, transplanting the turi seedlings, applying Rhizomax, plant maintenance, observation, and data collection.

Preparation of the Seedbed Medium

The growing medium used in this study was ultisol soil taken from the Edu Farm of the Faculty of Animal Science, Universitas Andalas. Soil was collected from a depth of 20-30 cm below the surface, with an initial pH of 5.31 and nitrogen content of 5.39%. The soil was then air-dried and cleaned of twigs, leaves, stones, and other unwanted material. It was next sieved so that it had a uniform size and texture, making it easier to mix evenly. Once homogeneous, 1 kg of ultisol soil was placed into a plastic seedling tray.

Selection of Turi Seeds

Turi seeds were first sorted to check their quality. This sorting separated good seeds from those that were damaged or diseased. After the seeds to be used as seedlings were selected, they were soaked before sowing.

Soaking the Turi Seeds

Turi seeds were soaked in a bottle of clean water (20-26°C) for 24 hours to break seed dormancy, since turi seeds have a hard seed coat [11]. After soaking, the seeds were strained and rinsed with clean water, then air-dried before sowing.

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Sowing the Turi Seeds

White turi seeds were sown in 20 x 20 cm plastic seedling trays. Before use, small holes were made in the top and bottom of each tray using a soldering iron to allow proper water drainage.

The seedbed medium, consisting of 1 kg of ultisol soil and 1 kg of sand, was mixed until homogeneous. Twenty planting holes, each 0.9-1.2 cm deep, were made in each tray, and one seed was placed in each hole before being lightly covered with soil (not compacted). The tray was then watered using a spray bottle and covered with clear plastic with 2-5 small holes to maintain humidity. Once shoots appeared, the plastic cover was removed. Seedlings were kept in the tray for two weeks before being transplanted into polybags.

Transplanting the Turi Seedlings

One day before transplanting, polybags were filled with 10 kg of growing medium each. Planting holes were made in 18 polybags. Each seedling, together with the soil surrounding its roots, was placed upright into a hole and covered with additional soil around it. The polybags were kept in a shaded area, and once new leaves appeared, they were moved to a partially shaded location.

Application of Rhizomax

In an earlier study, [10] applied PGPR (Rhizomax) at doses of up to 300 ml per plant, combined with manure and inorganic NPK fertilizer. In the present study, only Rhizomax was applied, at doses of up to 400 ml per plant. Rhizomax was applied by dissolving 50 grams of the product in 10 liters of distilled water, following the product instructions, and then pouring the solution around the root zone of each plant according to the assigned dose. Rhizomax was applied when the plants were two weeks old and again when they were transplanted into polybags.

Plant Maintenance

Maintenance activities included watering the plants twice a day and removing weeds around them. Watering used the same daily dose of 1 liter of water per polybag [10].

Soil Sampling

An initial soil sample was taken before treatment to serve as a baseline. Soil samples for each treatment were then collected when the plants were 9 weeks old. Each soil sample, weighing 5 grams, was used to measure the pH and nitrogen content of the soil after planting.

3. Results and Discussion

Soil test results before and after the study show that applying Rhizomax to white and red turi affected the chemical properties of the ultisol soil, as presented in Table 1 and Table 2 below.

Table 1. Soil Nutrient Content Before and After the Study on White Turi

Treatment	pH (before)	pH (after)	N % (before)	N % (after)
P0 (control)	5.31	5.24	5.39	4.83
P1 (100 ml)	5.31	5.45	5.39	5.11
P2 (200 ml)	5.31	5.56	5.39	5.39
P3 (300 ml)	5.31	5.29	5.39	5.67

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Treatment	pH (before)	pH (after)	N % (before)	N % (after)
P4 (400 ml)	5.31	5.65	5.39	6.23

Source: Solid Waste Laboratory, Environmental Engineering, Limau Manis Campus, 2026.

Table 2. Soil Nutrient Content Before and After the Study on Red Turi

Treatment	pH (before)	pH (after)	N % (before)	N % (after)
P0 (control)	5.31	5.35	5.39	4.13
P1 (100 ml)	5.31	5.75	5.39	4.27
P2 (200 ml)	5.31	5.78	5.39	4.69
P3 (300 ml)	5.31	5.83	5.39	5.25
P4 (400 ml)	5.31	5.86	5.39	5.81

Source: Solid Waste Laboratory, Environmental Engineering, Limau Manis Campus, 2026.

Based on the tables above, the ultisol soil had an initial pH of 5.31 and a nitrogen content of 5.39% before the study began, for both the white and red turi plots. These figures indicate that the soil was slightly acidic with a moderate level of nitrogen, which matches the typical characteristics of ultisol soil, namely acidic reaction and limited nutrient availability.

After treatment, both the pH and the nitrogen content changed in each treatment group. In the control group (P0), the soil pH of the white turi plot slightly decreased to 5.24, while the red turi plot slightly increased to 5.35. Meanwhile, the nitrogen content dropped to 4.83% for white turi and fell more sharply to 4.13% for red turi.

This decrease in the control group is thought to result from nutrient uptake by the plants and from soil microbial activity, which produces organic acids during decomposition. Because no additional soil-fertility inputs were given, nitrogen was used only by the plants during growth, and some nitrogen was also lost through leaching, which commonly occurs in acidic soils [6]. The low nitrogen level in P0 likewise reflects nitrogen being taken up by the plant for vegetative growth without any external addition.

Ultisol soil is generally low in nitrogen. This matters because turi plants need nitrogen to support their growth and development. According to [7], nitrogen is a key macronutrient for plants because it plays a role in forming chlorophyll, protein, and protoplasm, and therefore stimulates vegetative growth such as leaf and stem development. A lack of nitrogen can slow plant growth and cause the leaves to turn yellow.

The presence of legumes such as turi helps improve ultisol soil and plays an important role in raising its pH. Turi belongs to the legume family, which can form a symbiotic relationship with nitrogen-fixing bacteria in its roots. According to [5], legumes can improve soil fertility through biological nitrogen fixation, a process in which symbiotic microorganisms in the root nodules capture nitrogen from the air. Even so, turi still needs nitrogen already present in the soil to grow well, especially during its early growth stage and on nutrient-poor soils such as ultisol.

Applying Rhizomax to both white and red turi affected the chemical properties of the ultisol soil. Soil pH in treatments P1, P2, P3, and P4 was 5.45, 5.56, 5.29, and 5.65 respectively for white turi, and 5.75, 5.78, 5.83, and 5.86 respectively for red turi. Meanwhile, nitrogen content in those same treatments was 5.11%, 5.39%, 5.67%, and 6.23% for white turi, and 4.27%, 4.69%, 5.25%, and 5.81% for red turi.

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Applying Rhizomax increased soil pH overall, with the highest increase found in treatment P4 (400 ml per plant), reaching 5.65 for white turi and 5.86-5.89 for red turi. In general, the higher the dose of Rhizomax applied, the higher the soil pH tended to rise, with the exception of treatment P3 in white turi, where a slight decrease was observed.

The rise in pH and nitrogen content is likely linked to the activity of microorganisms such as Rhizobium contained in Rhizomax, which can capture nitrogen from the air and release hydroxide ions (OH-) into the soil [5], while also speeding up the decomposition of organic matter and the mineralization of nitrogen, thereby increasing nutrient availability in the soil [8]. The resulting pH values fall within a suitable range for turi growth; according to [9], turi (Sesbania grandiflora) grows well at a soil pH of between 5.5 and 7.5, meaning the pH levels obtained in this study still fall within a tolerable range that supports turi growth. These results indicate that using PGPR on ultisol soil, whether planted with red or white turi, can raise soil pH, and that this rise in pH opens a significant opportunity for making better use of ultisol soil on a wider scale.

4. Conclusion

This study found that the optimal dose of PGPR (Rhizomax) that raised soil pH and nitrogen content the most was 400 ml per plant. However, in terms of efficiency, the 200 ml per plant dose (P2) also produced a fairly significant increase in nitrogen while using the inoculant more efficiently.

5. Recommendations

Further research is recommended that includes additional parameters, such as available phosphorus, available potassium, organic carbon, and the number of effective root nodules, in order to gain a more complete picture of Rhizomax's effect. Field trials on farmers' land are also recommended to confirm the effectiveness of Rhizomax under real-world ultisol soil conditions.

Declarations

Author Contributions

Conceptualization, Methodology, Investigation, Writing – Original Draft: Mardhiyetti; Supervision, Validation, Writing – Review and Editing: Novirman Jamarun. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Abstract

Rice straw is still widely burned in Indonesia because smallholders lack an incentive to collect, store and process it, and extension programs that teach composting or feed fermentation often fade when facilitators leave. This article develops the Straw Bank, a commodity-savings social business in which farmers deposit straw and withdraw cash or compost while local youth process it into compost and fermented feed, into a testable business model for Solok City, West Sumatra. Following a design science approach, we combine official statistics, peer-reviewed studies and legal texts for a situation analysis, and adapt the Business Model Canvas with an impact block and a surplus-reinvestment rule drawn from social enterprise and sustainable business model canvases. The analysis shows that 16.89 million of 28.42 million agricultural business households are smallholders farming less than 0.5 ha; that the food-crop farmer exchange rate (119.24 in September 2026) is below the national average (131.11); that incorporating straw into flooded paddies can raise net warming potential above that of burning; and that evidence from other countries suggests barter-type rewards can work. The resulting canvas separates straw suppliers from product buyers, makes the straw savings account the core value mechanism, and starts with compost and fermented feed. A three-stage test plan with seven falsifiable hypotheses and three continue-or-stop gates is proposed. The model is not yet field-proven and no primary data are reported. The article contributes a transferable design and a pilot protocol with pre-specified thresholds for commodity-savings schemes that manage seasonal agricultural residues.

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Keywords: rice straw, social business, business model canvas, agricultural waste, smallholder farmers, West Sumatra

1. Introduction

Rice straw is still treated as a residue to be removed quickly, although it is a biomass resource available after every harvest. In 2025 Indonesia harvested about 11.32 million hectares of paddy and produced 60.21 million tonnes of milled dry grain (GKG) [1]. Every harvested hectare leaves straw that must be managed before the next tillage.

Open field burning of rice straw remains widespread worldwide [2]. In Indonesia, open burning of crop residues releases carbon dioxide, carbon monoxide, methane, nitrous oxide and particulate matter [3]. A global survey of life cycle assessments concludes that soil incorporation and electricity generation are among the most environmentally friendly alternatives [2], but field evidence shows that incorporating straw into flooded paddies can raise methane emissions enough to outweigh the benefit of not burning [4], [5] (Section 4.1.2).

The problem is not simply a lack of technology. Composting, fermented feed and mushroom substrate have long been available, yet adoption stays low. Among farmers in Magelang who already fed straw to ruminants, only 3.37% fermented it [6], and a recent community intervention in Jember reached a farmer group in which every member still burned straw after harvest, with a single socialization session as the intervention [7]. Reviews of straw management stress that technologies work only when supporting value chains and business models exist [8]. We therefore propose that the binding constraint is the absence of an incentive structure: farmers see no certain buyer, no clear price and no organization that collects the straw. This proposition is tested, not assumed, in the plan presented here.

The Straw Bank concept was first sketched in a 2020 course assignment at Universitas Andalas for Solok City, West Sumatra (unpublished). Farmers could sell their straw or "save" it in exchange for compost, while local youth are trained to process it into valued products. The term "Straw Bank" has also appeared as a proposal in the Jember intervention cited above [7], which did not develop it into a business model or test it. This article develops the concept into a testable social business design with three additions: a situation analysis based on current data, an adaptation of the Business Model Canvas (BMC) that includes social and environmental impact, and a staged test plan with continue-or-stop criteria.

Existing literature addresses straw management technologies, emissions and logistics [8], [2]; canvases for social and sustainable ventures [9], [10]; and Indonesian waste banks as social business models [11]. To the best of our knowledge, no study has yet designed a commodity-savings social business for a seasonal agricultural residue such as rice straw, with an impact block, a surplus rule and pre-specified test gates. This article addresses that gap.

Three research questions guide the study. RQ1: Which farmer problem does the Straw Bank actually solve? RQ2: What social business model is consistent with that problem? RQ3: How can the model be tested before major funds are committed? The contribution is threefold: (i) a situation analysis that corrects two common over-simplifications, namely that incorporating straw is automatically low-emission and that a low farmer exchange rate means low farm income; (ii) a canvas adapted for a commodity-savings social business; and (iii) a falsifiable pilot protocol with seven hypotheses that practitioners can run directly. Section 2 reviews the literature, Section 3 explains the method, Section 4 presents the analysis, model and test plan, and Section 5 concludes.

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2. Literature Review

2.1. Rice straw management: options and trade-offs

After harvest, straw can be removed, burned, piled or spread, or incorporated into the soil, and removed straw can feed ruminants, grow mushrooms, become compost, or supply energy and material industries [8], [2]. These options differ in emissions and economics. A field experiment in the Philippines found that incorporating straw into flooded paddies produced a higher annual global warming potential (8,023 kg CO_2-eq/ha) than burning (4,913) or removing the straw completely (3,470), counting methane and nitrous oxide only [4]. A meta-analysis of field studies likewise reported that adding straw increased methane emissions by about 153% and rice yield by about 7% [5], and the IPCC inventory guidelines distinguish methane emission factors for paddies by the timing of straw incorporation relative to planting [12]. Life cycle surveys, by contrast, rank soil incorporation among the best options [2]. These findings are not necessarily contradictory; they probably differ in system boundaries and water regime, which is why emission claims must be tied to a defined baseline scenario. Straw is also a poor feed because of its silica and lignin content, so treatment is needed to raise its nutritive value [13].

2.2. Social enterprise and business model canvases

The BMC describes how an organization creates, delivers and captures value through nine blocks [14]. For ventures whose primary goal is social, the Social Enterprise Model Canvas adds impact measurement, non-target stakeholders and governance to prevent mission drift [9], and the Triple Layered Business Model Canvas adds environmental and social layers to the economic one [10]. Social business, as articulated from the Grameen experience, places social value as the objective and financial sustainability as a condition [15]. Hybrid organizations that combine social goals with market mechanisms face mission drift, and dual governance and accountability are considered keys to preventing it [16]. Because the effectiveness of a business model can only be established empirically, lean-startup logic recommends turning assumptions into hypotheses and testing them with the cheapest experiments [17], [18].

2.3. Savings-based collection and farmer supply behaviour

Waste banks are the closest Indonesian institutional analogue to a savings account for a used commodity. A case study of the Surakarta Waste Bank applied a business model canvas to combine a social-environmental mission with business principles [11]. For straw specifically, evidence on farmers' willingness to supply is instructive. In northeast China, the price at which farmers were willing to sell straw depended on current use: it was higher for productive uses such as feed, fuel or sale, and lower when the straw was burned in the field [19]. In Sweden, willingness to sell depended on end use, farmers preferred benefits such as manure in barter arrangements over bioenergy, and supply was not highly price-sensitive [20]. These studies come from contexts different from Solok, but they point to reward design, notably barter, as a lever.

2.4. Synthesis

The literature thus offers technology and emission evidence with conflicting implications for straw incorporation, canvases adapted to social ventures, and supply-behaviour evidence from other countries. It does not offer an integrated design for a savings-based social business for rice straw in Indonesia. Section 3 describes how we build one.

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3. Methodology

3.1. Research design

This is a design study based on secondary data, not a field report. No primary data are reported. We follow the design science research methodology [21]: identifying the problem and its motivation, defining objectives for a solution, designing an artifact (here, a business model canvas and a test protocol), and preparing demonstration and evaluation, with empirical evaluation deferred to the pilot (Section 4.3). All market and cost figures for Solok are treated as hypotheses.

3.2. Data sources and literature search

Sources were identified through purposive, non-systematic searches in October 2026 of publishers' sites, indexing pages and official portals, using English and Indonesian keywords such as rice straw, straw burning, social enterprise, business model canvas, waste bank, willingness to sell straw, "bank jerami" and "pembakaran jerami". We included peer-reviewed journal articles and books, official statistics from Statistics Indonesia (BPS) and legal texts, and excluded news items and press releases as references. Figures were checked against the source page or abstract. Because the search was not systematic, relevant studies may have been missed (Section 4.4).

3.3. Model design

The initial design was reconstructed with the nine-block BMC [14] and extended with one impact block following the social enterprise and sustainable canvas literature [9], [10]. Each block was then converted into a falsifiable hypothesis with a measure and a continue-or-stop threshold, following customer-development and lean-startup logic [17], [18]. The reconstruction was carried out by the authors from the situation analysis; no external validation with stakeholders has yet been conducted, which is a limitation.

4. Results and Discussion

4.1. Situation analysis

Smallholders and thin margins. The 2023 Agricultural Census recorded 28.42 million agricultural business households, of which 16.89 million were smallholders ("gurem") operating less than 0.5 ha [22]. Taken at face value this is about 59%, although the share BPS reports may differ slightly depending on the denominator, and the count covers all agricultural subsectors, not only rice; the share among rice farmers in Solok must be computed from local data. Small plots imply small straw volumes per farmer, so individual transport is rarely sensible and collection must be organized through farmer groups or shared collection points. The straw volume per household remains to be measured. The national Farmer Exchange Rate (NTP) was 131.11 in September 2026, while the food-crop subsector stood at 119.24 [23]. NTP is the ratio of the index of prices received to the index of prices paid by farmers, not a measure of income, and the food-crop subsector includes secondary crops as well as rice. The figures therefore indicate that the exchange rate of food-crop farmers is lower than the national average; extra income from straw may matter to them, but they are also sensitive to additional work and cost. In West Sumatra, the paddy harvested area in 2025 was 284,076 ha, producing 1.383 million tonnes of GKG [24].

Burning, emissions and what is actually avoided. Open burning of crop residues releases greenhouse gases and air pollutants [3]. Two nuances matter. First, incorporation of straw in flooded paddies is not automatically low-emission [4]; the meta-analysis [5] and the IPCC guidelines [12] point in the same direction. The Philippine experiment did not count carbon monoxide, particles or the health impact of smoke, and off-field emissions from straw utilization lie outside its boundary. Second, the benefit of the Straw Bank is therefore not only "stop burning" but "remove and

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process straw outside the field", and any emission reduction claim must be measured against a defined baseline scenario (burning, incorporation or removal) rather than stated in general terms.

Product market space. Table 1 summarizes the candidate products.

Table 1. Candidate straw products, users and available evidence

Product	Users	Available evidence	Conditions for uptake
Fermented feed	Cattle and goat keepers	Among Magelang farmers using straw as feed, only 3.37% fermented it; training and herd size influenced adoption [6]. Straw is a poor feed owing to silica and lignin, so treatment is needed [13].	Demonstrated results, stable supply, price competitive with forage
Straw compost	Rice and vegetable farmers	Straw addition raised rice yield by about 7% in a meta-analysis, but also raised methane when added raw to flooded fields [5]; effects of compost at Solok are untested.	Uniform quality, price, and a channel that does not clash with subsidized fertilizer
Mushroom substrate	Mushroom growers	Not assessed with peer-reviewed evidence in this study; candidate for a later phase.	Local buyers and cultivation skills
Briquettes, biochar, crafts	Industry, artisans	Densification and thermochemical conversion are discussed as value-adding options [8]; feasibility at Solok not assessed.	Scale and machine investment; deferred until the first pilot is stable

Fertilizer pricing shapes the position of compost. The government cut the retail ceiling price (HET) of subsidized organic fertilizer from IDR 800 to IDR 640 per kg from 22 October 2025 [25]; this applies to fiscal year 2025 and the current ceiling must be checked at submission. Straw Bank compost should therefore not compete head-on with that price. It is more plausible as a medium of exchange for straw savings, as compost for higher-value crops, or as supply to authorized distributors when standards are met.

Seasonal feed supply is often cited as the strongest "banking" logic: store straw at harvest and sell it when forage is scarce. The evidence we found for such scarcity concerns seasonally dry regions, whereas West Sumatra is relatively humid, so the scarcity may be weaker. We therefore treat seasonal arbitrage as a hypothesis to be tested at Solok (H3) rather than as a proven source of value.

Lessons from similar models. Three design lessons follow from the evidence. First, waste banks show that a savings-based collection institution can be framed as a social business using a canvas [11]; the difference for straw is that it is seasonal, bulky and low in value per unit weight, so transport and storage costs will probably decide viability. Second, barter-type rewards are acceptable to farmers in other contexts [20] and willingness to accept depends on current use [19], which supports offering compost in exchange for straw but requires testing at Solok (H1). Third, straw management technologies are sustained when value chains and business models are in place [8], so a collection point managed by a local group is probably the critical node; we treat this as a hypothesis (H2, H5).

Regulation. Article 69(1)(h) of Law 32/2009 prohibits land clearing by burning, and paragraph (2) requires attention to local wisdom, which the Elucidation limits to a maximum of two hectares per household with fire breaks [26]. The provision regulates land clearing, not post-harvest straw burning, so its application to straw is unclear and should be examined with the local environment agency and regional regulations. The Straw Bank is therefore positioned as an attractive alternative, not as enforcement of a ban.

Data gaps. Three key data are missing and must be collected at Solok: the straw volume actually available and burned per hectare, the prices of straw and compost that local users are willing to pay, and the cost of transport and

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storage. Production data at Solok City level were not obtained from the sources consulted; provincial data are given above [24].

4.2. Proposed business model canvas

The Straw Bank is designed as a social business: farmers deliver straw and receive money or compost, local youth process it, and surplus is reinvested in the venture. Figure 1 shows the canvas, which reads from the centre: the value proposition serves four parties at once, and the impact block at the bottom is a yardstick of success alongside profit.

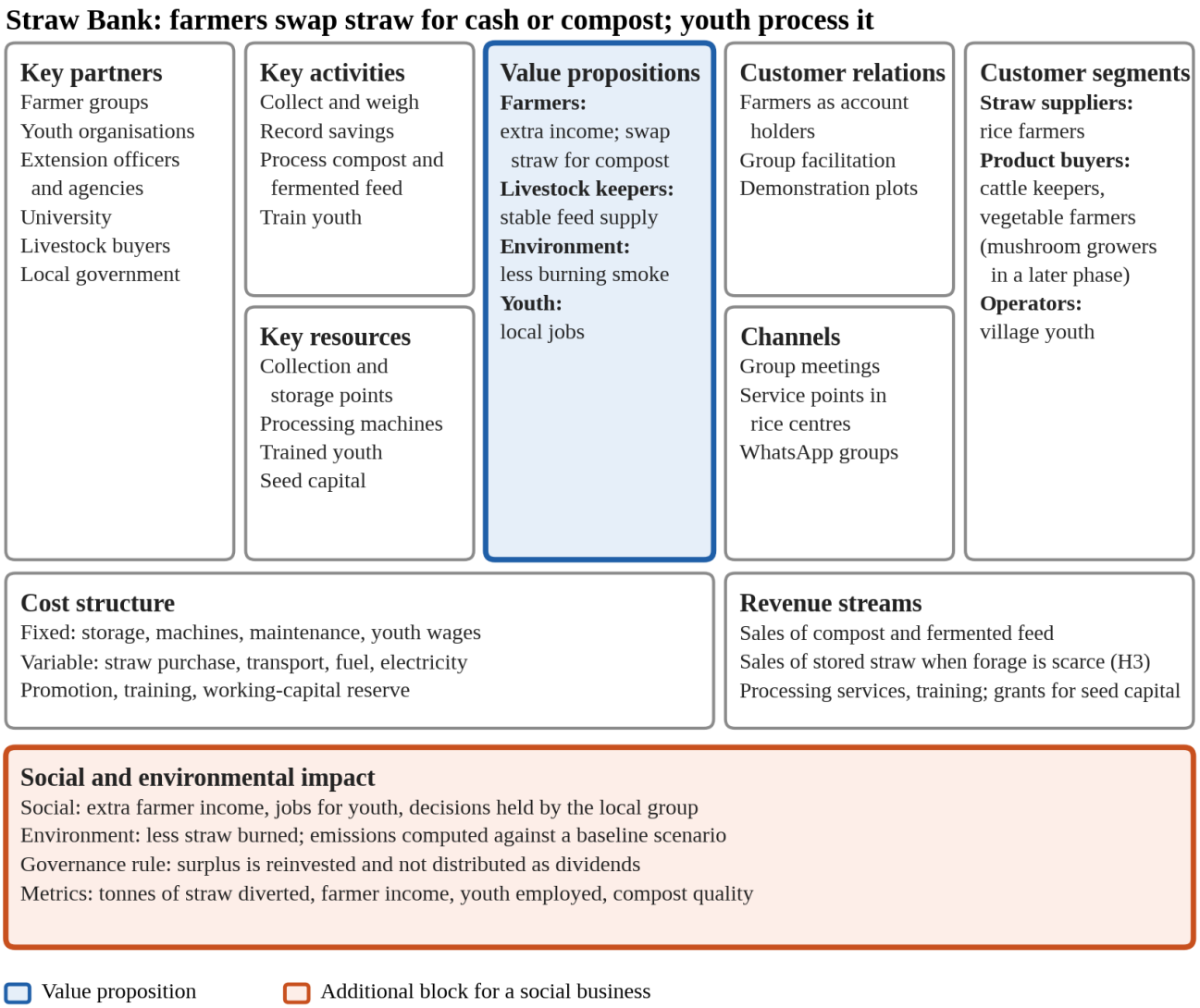


Figure 1. Business Model Canvas of the Straw Bank: nine blocks plus one impact block. Adapted by the authors from [14], [9].

Changes from the 2020 concept. Customers are split in two: rice farmers are straw suppliers, while cattle keepers, vegetable farmers and, later, mushroom growers are product buyers; the 2020 concept mixed the two. The "straw savings account" is made concrete: straw is weighed, recorded and redeemed as cash or exchanged for compost. Storing straw at harvest and selling it when forage is scarce is retained as a hypothesis (H3), not a premise. Products

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are narrowed to compost and fermented feed, and briquettes, biochar and crafts are deferred. One block is added: an impact block with four fields (social outcomes, environmental outcomes, a governance rule on the use of surplus, and metrics), which keeps the mission from drifting into an ordinary business [9], [10].

Why it is a social business. Three features distinguish it from an ordinary straw trading business. Its primary purpose is to reduce burning and raise the incomes of farmers and youth, not to maximize profit. It must cover its costs from sales so that it does not stop when grants and facilitators leave, which we hypothesize is the weakness of earlier community programs. Surplus returns to the venture to expand its reach, consistent with the social business principles of the Grameen experience [15]. Management is held by local youth and farmer groups, with external partners as facilitators, and a rule on the use of surplus together with group decision-making guards against mission drift [16]. The legal form (cooperative, village-owned enterprise, company or foundation) is still open and determines how the no-dividend rule can be enforced.

4.3. Test plan

The model is feasible if seven hypotheses hold at small scale, tested in an order that examines the riskiest assumptions first, following customer-development logic [17], [18]. Figure 2 shows three stages and three gates, and Table 2 lists the hypotheses. The thresholds are initial proposals, not findings; they should be agreed with farmer groups and youth before Stage 1 begins and then locked, so that decisions do not shift after data arrive.

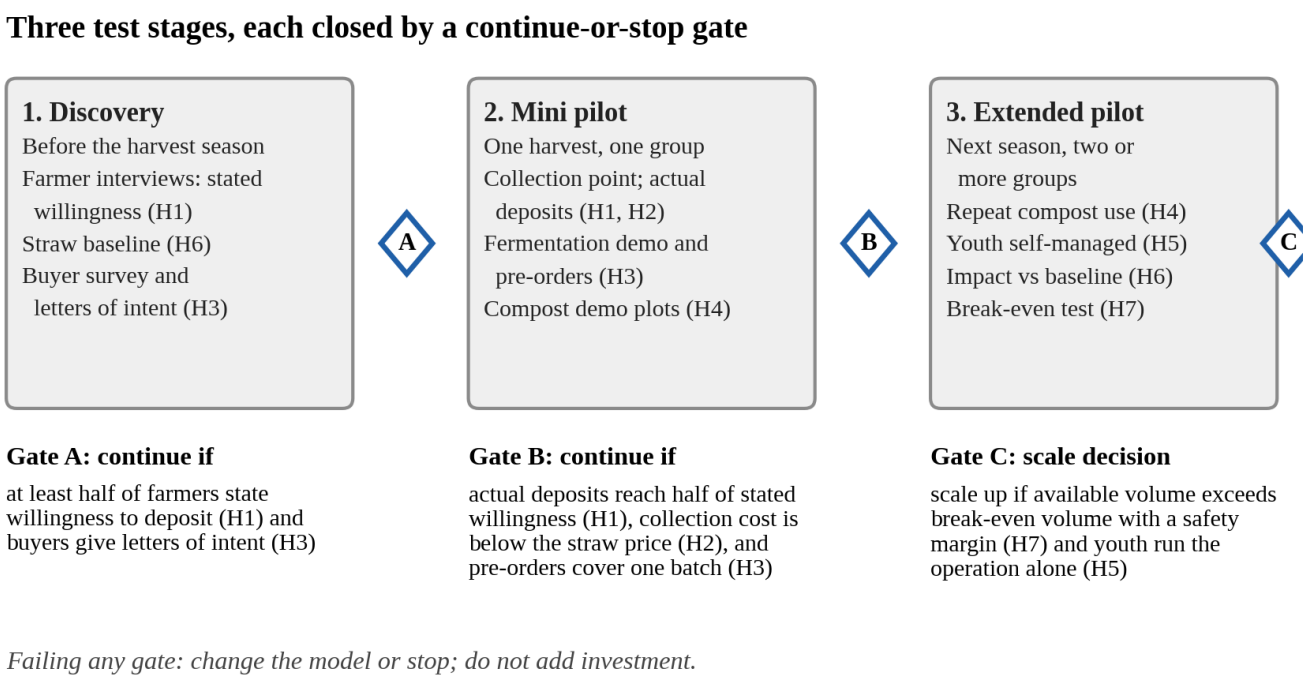


Figure 2. Three test stages, each closed by a continue-or-stop gate (A, B and C).

Table 2. Hypotheses, tests and proposed continue-or-stop thresholds

ID	Hypothesis (canvas block)	Test and stage	Measure	Proposed threshold (gate)

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ID	Hypothesis (canvas block)	Test and stage	Measure	Proposed threshold (gate)
H1	Farmers will deposit straw for cash or compost (segments, relationships)	Stage 1: interviews with smallholder and other farmers (stated willingness). Stage 2: invitation to deposit at one harvest (revealed behaviour)	Share stating willingness; share actually depositing	A: at least half state willingness. B: actual deposits reach half of stated willingness
H2	Straw can be collected at reasonable cost (activities, cost)	Stage 2: one collection point for one farmer group during one harvest	IDR and labour hours per tonne collected	B: collection cost per tonne below the straw price buyers pay
H3	Livestock keepers pay for fermented straw (revenue)	Stage 1: buyer survey and letters of intent. Stage 2: fermentation demonstration and pre-orders	Number and volume of orders; agreed price	A: buyers give letters of intent. B: pre-orders cover the cost of one batch
H4	Farmers use straw compost repeatedly (value proposition, revenue)	Stage 2: demonstration plots against farmers' practice, offered through straw exchange. Stage 3: following season	Yield, repurchase, satisfaction	C: repurchase in the following season
H5	Youth can manage without external facilitators (resources, partners)	Stage 3: training, then phased withdrawal of facilitators	Attendance, record accuracy, turnover	C: operation runs alone for one full cycle
H6	Environmental impact can be demonstrated (impact block)	Stage 1 baseline; Stage 3 endline; comparison group	Tonnes diverted, hectares unburned, emissions against a baseline scenario	C: baseline and endline data for every group
H7	The venture covers its own costs (cost, revenue)	Stage 3: break-even computed from H2–H4 data	Break-even volume against available volume	C: available volume exceeds break-even with a safety margin

*Thresholds are initial proposals to be agreed with farmer groups before Stage 1.

Break-even volume and savings liability. The break-even volume of processed output per period follows from fixed cost and unit margin:

$$Q^* = \frac{F}{p - v} \tag{1}$$

where F is the fixed cost per period (storage, machines, youth wages, impact measurement), p is the average selling price per tonne of product, and v is the variable cost per tonne (straw purchase, transport, fuel). F, p and v are unknown without field data, so no estimates are inserted here. Because this single-product linear model is simple, the pilot should extend it to two products, seasonal volumes and storage costs, with scenario or sensitivity analysis using ranges from the field and the literature [8]. A particular risk concerns the savings liability: straw "saved" by farmers is an obligation to hand over compost or cash later. The value of unredeemed savings must be recorded and capped at the cash and stock the venture holds, so that farmers' trust, the main asset of the venture, is not damaged. Because redeemable savings may touch cooperative or fund-collection rules, legal advice is needed before launch.

Measuring social and environmental success. Besides finance, three indicators are reported every season: additional income per participating farm household, the number of youth earning from the venture, and the tonnes of straw diverted from burning. All are compared with baseline data collected before the program starts; without a baseline, impact claims cannot be defended. Attribution should be strengthened with a comparison group or a difference-in-differences design, and emissions should be computed against the baseline scenario using emission factors from the IPCC guidelines [12] or local studies.

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4.4. Discussion

The strength of the design lies in one shift: straw is treated as a good that is stored and sold rather than as waste. From that shift, farmers would gain an economic reason to release straw that does not depend on facilitators being present; this remains a proposition for the pilot to test. Burning is not the only adversary. Incorporating straw into flooded fields can raise net warming more than burning [4], [5]. A robust case for the Straw Bank is therefore a combined one: smoke and nutrient loss fall, and straw removed and processed outside the field curbs paddy methane. This must be demonstrated at Solok with baseline data rather than imported from the Philippines.

Compared with waste banks [11], the design adds a seasonal-commodity logic and pre-specified gates; compared with social and sustainable canvases [9], [10], it adds a savings-account value mechanism; and compared with straw supply studies [19], [20], it embeds the choice of reward in a testable organization. Theoretically, it shows how social canvases can be adapted to a seasonal, bulky commodity. Practically, the protocol is ready for a pilot with farmer groups, youth organizations and extension officers. For policy, regional environment and agriculture agencies could support collection points, and the pricing of subsidized fertilizer shapes the role that compost can play.

Main risks and how they are handled. **Volume and season:** paddy harvest is seasonal, so straw arrives at once and storage fills quickly; H2 must record storage capacity and moisture. **Compost versus subsidized fertilizer:** at the subsidized ceiling price, paid compost can hardly win on price; it is marketed through straw exchange and for high-value crops, and the pilot tests willingness to pay before machines are bought. **Feed adoption:** fermented feed is not yet a habit, as the Magelang figures show [6], so demand must be built through demonstration rather than assumed. **Mission drift:** if the venture is taken over by capital-rich actors, youth and farmers could be displaced; the surplus rule and local group decisions are written into the canvas. **Trust:** savings that cannot be redeemed will stop deposits, so the savings liability is capped by cash and stock.

Funding opportunities. Carbon markets and low-emission rice schemes could provide additional income but are not included in the canvas, because their technical rules and measurement methods for straw were not verified in this study. They deserve review once baseline and pilot data exist.

Limitations. The design rests on secondary data. Part of the evidence on straw utilization comes from other countries (the Philippines, China and Sweden), some peer-reviewed sources were read at abstract level, the literature search was not systematic, and no Solok City-level data were obtained. The canvas has not been validated with stakeholders, and the provisions on burning in the regulatory landscape may change. The earlier concept on which this article builds is unpublished.

5. Conclusion

The Straw Bank merits testing as a social business because it addresses a real problem of smallholder rice farmers: straw has little value to them, and processing programs are not sustained without an incentive. In answer to the research questions, the proposed problem is the missing incentive and organization for collecting straw (RQ1); the consistent model is a canvas that separates straw suppliers from product buyers, makes the savings account the value mechanism, starts with compost and fermented feed, and includes an impact block with a surplus rule (RQ2); and the model is tested through seven hypotheses, three stages and three gates agreed in advance (RQ3). The model is not yet field-proven.

For field practice we recommend four steps. First, collect baseline data at Solok before any investment: straw volume per hectare, current practices, the prices of straw and compost, and livestock keepers' willingness to pay. Second, run the three test stages and agree the thresholds before Stage 1 starts. Third, involve farmer groups, youth organizations,

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extension officers and the university from the design stage, because sustainability is determined by local management. Fourth, review carbon finance and organic fertilizer programs after the baseline and pilot results are available. Future research should replicate the protocol in other humid tropical sites, measure emissions by scenario, and compare legal forms for the venture.

6. Declarations

6.1. Author Contributions

Conceptualization: all authors; Methodology: F.A.; Writing – Original Draft: F.A.; Writing – Review and Editing: S.A.

6.2. Data Availability Statement

No new data were generated in this study. All data analyzed are from the published sources cited in the References.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable. No human participants were involved in this study; the pilot described in Section 4.3 will require ethical review before data collection.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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