

Economic and Environmental Well-Being for Smallholder Farmers: Can We Avoid Worse-Before-Better Dynamics In Transitioning To Organic Farming?

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ABSTRACT

Agriculture, and hence choices made by a farmer, has a significant impact on environmental sustainability. Presently, more than 98% of farmers in India follow conventional farming using chemical fertilizers, often to the detriment of the environment, yields, and personal health. They remain hesitant to adopt organic farming despite its promise of greater sustainability and profitability. Allegedly, their reluctance stems from the debilitating consequences of a “worse-before-better” (WBB) scenario, where agricultural yields—and therefore income—decline temporarily during the transition from conventional to organic farming. Already organic farmers, however, refute such a notion as a myth. In this context, our research investigates: *under what conditions is the transition from conventional to organic farming most favorable to the farmer?* We build a dynamic model of the transition from conventional to organic wheat farming system, derived from literature as well as interviews with wheat farmers in Haryana, India. Our analysis first reproduces the WBB dynamics. We then suggest how factors like cost of organic farming, time to revive soil health after over fertilization, and rate at which land is converted could be used to achieve the right balance of the duration of and the profits lost during the transition for a smallholder farmer.

INTRODUCTION

The environmental and social impacts of the global agriculture system are significant, and there is widespread agreement that more sustainable practices will be necessary to adequately feed the growing population. In terms of the environmental impact, the global agricultural industry consumes 40% of the earth's land area (World Bank, 2012; Alston & Pardey, 2014), and the agricultural activity contributes massively to climate change as carbon dioxide is released when land is cleared, fossil fuels are burned to make fertilizers and run machinery, and livestock produce increasing amounts of methane gases. Alone, the agricultural sector is responsible for 10-12% of global anthropogenic GHG emissions, and this estimate goes up to 20-35% when accounting for the whole food and farming sector (i.e., fertilizer production, food transport and refrigeration, consumer practices, and waste management) (Paarlberg, 2010). Added to these externalities are issues of soil erosion, water pollution, and loss of biodiversity.

In terms of social impact, agriculture provides livelihood for 2.6 billion people globally. While it is very hard to estimate the total number of farms and farm sizes worldwide owing to the division of land holdings that occurs from generation to generation, according to FAO's 2014 estimate there are an 570 million farms worldwide. Approximately 85% of the farms are family farms, while the rest are non-family (i.e., corporate farming) entities. Most importantly, 82% of all farmers are smallholder farmers who own less than two hectares of land and therefore have minimal risk bearing capacity (Lowder, 2014).

The picture is similar in India where the current research is focused. In India, agriculture accounts for 52% of employment and 18% of income, and 86% of the farmers are smallholder farmers (World Bank, 2012). Since the 1960's when the Green Revolution introduced modern agricultural technologies such as irrigation, improved seeds, fertilizers, and pesticides to India, conventional farming has become the status quo. Though Green Revolution technologies such as synthetic nitrogen fertilizer increased crop yields on existing land, it has led to reliance on, and over usage of, chemical inputs that is environmentally degrading (IAASTD, 2008). These chemical-based agricultural practices have been shown to have a negative environmental impact, including adverse health consequences for farm laborers, soil erosion, water pollution, air pollution, and loss of biodiversity (Yedla and Peddi, 2003; Amundson, 2015).

Though the chemical usage that characterizes *conventional farming systems* can inflict negative consequences on the environment, farmers are attracted to these methods because of the high yields they can produce on existing land. In contrast, in an *organic farming system*¹ manure-based fertilizers are created, often on the farm,

¹ Definitions of organic agriculture vary slightly between certification agencies and agricultural bodies (IFOAM, 2002; FAO Codex Alimentarius Commission, 2001; USDA, 2008); however, most agree that organic farming is an agricultural production method that promotes soil health without the use of synthetic inputs. In India, there are nationally and internationally accredited organic certifying

and substituted for nitrogen-based chemical fertilizer purchased off the farm. The rich nutrient composition within these organic fertilizers increases both biophysical (e.g., Soil Organic Matter) and biological (e.g., biodiversity; biomass) aspects of soil health (Briar et al., 2007; Gomiero et al., 2011; Marriott and Wander, 2006). Organic practices have been shown to provide environmental benefits.

It is increasingly clear that relying solely on chemical-based agricultural systems will have negative environmental consequences, and that organic practices can eliminate negative environmental impacts. Moreover, recent research has argued that it may make better economic sense to grow several crops using the organic farming system (Tej Pratap, 2009). Figure 1, below, compiled from Tej Pratap and C. S. Vaidya's survey of 27 different crops grown under conventional vs. organic farming systems in India,² shows that 14 of these crops, *in equilibrium*, have higher cost of cultivation and lower net profits when grown under conventional system. In other words, for these crops (marked in blue font), it would be better to use organic practices. Despite these observations, however, less than 1% of India's land is under organic farming (Paull, 2011). Why is this the case?

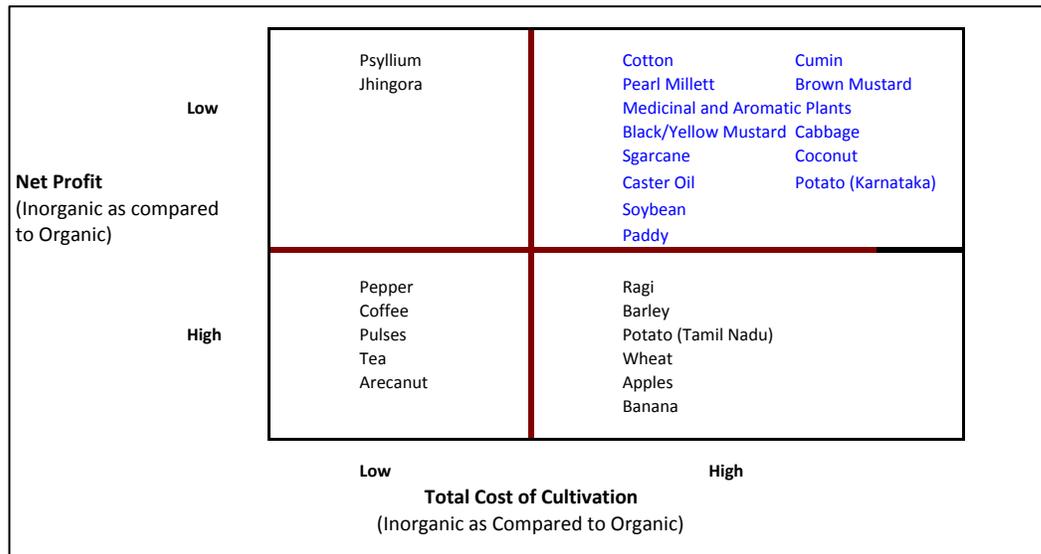


Figure 1: Conventional (i.e., inorganic) vs. Organic Farming In Equilibrium (Tej Pratap 2009)

The current research is focused on investigating *the behavioral dynamics* behind this situation. The remainder of this paper is organized as follows. We first distill further the research question and the debates surrounding it, and outline the methodology. We then provide an overview of the economic, environmental, and

agencies (e.g., National Programme on Organic Production (NPOP); Agricultural and Processed Foods Export Development Authority (APEDA); International Movement of Organic Agriculture Movements (IFOAM)).

² Precisely, we have compiled results presented in Tables 1-27 of Chapter 5 of the Tej Pratap 2009 reference. The percentage difference in cost of cultivation and net profit is presented in Appendix I.

behavioral dynamics that govern farming systems in India. Next, we present the dynamic model, including formulations for key model equations and model parameterization. We then explore numerous scenarios of transition from conventional to organic farming, and conduct a sensitivity analysis to illuminate factors influencing the depth and timing of the worse-before-better effect. Finally, we comment on current limitations, and suggest next steps for model refinement and policy analysis.

RESEARCH QUESTION AND METHODOLOGY

A commonly held hypothesis is that farmers are deterred from organic practices due to the fear of a “worse-before-better” (WBB) dynamic³ (SystemDynamics.org), where agricultural yield--and subsequently income-- initially drops before recovering (or even surpassing) previous levels. The fundamental reason behind this belief may be the disagreement about how farm productivity differs under conventional vs. organic systems. Current research on the yield potential of organic farming is often conflicting. Some NGOs and environmental activist groups, as well as scientists, claim that under optimal organic practices, a farmer can increase profits and improve environmental health (e.g., Altieri, 2009). Other research has found that organic farming systems are inherently less efficient than chemical-based systems, and therefore only with subsidies, price premiums, or adoption of animal husbandry to produce on-farm inputs can a farmer realize economic advantages (Uematsu and Mishra, 2012; Giovannucci, 2005; Nemes, 2009).

Additionally, it has been argued that the adoption of organic farming is inhibited by informational, social, and market-related factors such as: inadequate access to technical knowhow about organic farming, lack of awareness about the pros and cons of conventional and organic farming systems, non-availability of organic inputs, lack of knowledge of market opportunities for organic produce, and farmer’s negative perception of organic systems. Here too, there are wide range of responses recorded across different regions and crops (for a good summary of socio-economic factors in the Indian context see Tej Pratap and C. Vaidya 2009). Overall, to our knowledge, no systematic synthesis of these factors, explaining how they relate to the feared worse-before-better scenario, exists. The current research therefore investigates the following question: *under what conditions is the transition from conventional to organic farming is most favorable to the farmer?*

To answer this question, we first build a dynamic model that shows the necessary conditions for a farm to exhibit worse-before-better behavior *during transition* from conventional to organic farming. The model was derived from a review of current studies on organic farming, interviews with experts, and interviews with organic, conventional, and mid-transition wheat farmers in the state of Haryana.

³ <http://www.systemdynamics.org>

FARMING AND ADOPTION DYNAMICS

Organic and conventional farming systems share many aspects, as well as exhibit key differences. This section presents an overview of wheat farming in India, including the basic dynamics of both conventional and organic wheat farming systems. This section also outlines the factors governing adoption of organic farming, as well as the formulations for, and descriptions of, key model parameters. The complete model is available in Appendix III.

Wheat Production and Distribution

Wheat is an important crop to the Indian agricultural industry as well as the Indian diet. Wheat prices began to rise in 2009, and since then production and consumption continue to trend upwards (International Grains Council). During the 2013-14 seasons, India exported over five million metric tons of wheat (APEDA). Most of the wheat produced in India is produced in the North, in states such as Haryana where farms comprise 9.12% of India's wheat area and produce 14.12% of India's total wheat production (Wheat Bazar, 2013). The majority of wheat production in India follows conventional practices: synthetic nitrogen fertilizer is applied to increase plant growth, as nitrogen is essential for photosynthesis and protein development.⁴

The Food Corporation of India (FCI) is the main purchaser of wheat. The FCI was established in 1964 by the Government of India (GOI) to provide price support to farmers (i.e., Minimum Support Price, or MSP), distribute foodgrains and maintain foodgrain stocks to promote food security, subsidize the price of foodgrains for the food insecure, and stabilize foodgrain markets through interventions.

Wheat is a commodity crop and highly susceptible to weather, so profits for farmers are volatile. The FCI tries to mitigate this risk for farmers; for example, by relaxing the procurement standards for wheat to enable farmers to sell despite unusually late rains causing damage to the crop (USDA Foreign Agricultural Service, 2015). The FCI is therefore an attractive market for small-scale farmers who do not have the capacity to process their own wheat, or the flexibility to store wheat until prices stabilize. The FCI does not differentiate between organic and conventional wheat, so the MSP for wheat (i.e., the price farmers receive) is the same irrespective of production method.

Economics of Farming Systems

Figure 2, below, shows the basic dynamics of wheat farming. The profitability of a farm is determined by the income from the yield of the wheat crop, minus the cost of producing that yield. This creates two structures, one reinforcing and one balancing.

⁴ Though genetically modified wheat has been used in research studies in the United States, as of 2014, only just over half of the wheat genome has been sequenced and there is no GM wheat grown commercially (Feltman, 2014).

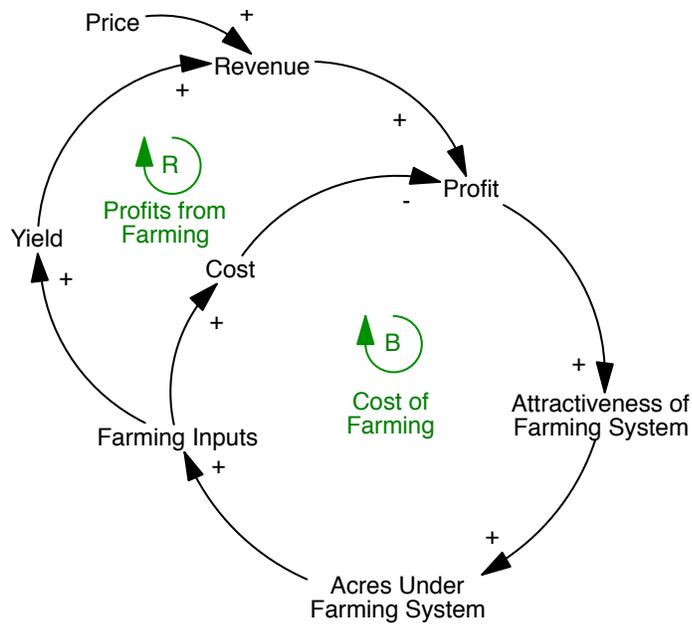


Figure 2: Economics of Farming Systems

The *Cost of Farming* loop in Figure 2 is a balancing structure: as more money is spent on inputs, costs increase and profits decrease. Both conventional and organic farming systems require seeds, water (i.e., irrigation), fertilizer, pest management, and labor. In conventional wheat farming, chemical fertilizers and pesticides are purchased off the farm and applied with minimal labor costs. In contrast, organic farmers use non-synthetic fertilizers made on the farm, such as vermicompost- a heterogeneous compost mixture that uses worms to decompose food waste and animal manure. Different groups promoting organic farming promote different practices given what is available in local environments. For this research, we observed techniques used by Organic Farming Organization (OFO), which promotes a package of practices that include using *panchagavya*, a combination of vermicompost and a fermented mixture of cow products including but not limited to manure, urine, and milk (Kumari et. al; Singh et. al, 2012; Singhal et. al, 2012). Organic farmers therefore do not generally purchase off-farm inputs; however, the labor involved in developing and applying these fertilizers, as well as in managing pests and weeds, is often higher than in conventional farming (FAO, 2002; Foster et al., 2006).

The *Profits from Farming* loop in Figure 2 is a reinforcing structure. As yields increase, profits also increase, and the attractiveness of the current farming system (conventional or organic) increases, causing the farmer to continue farming under the same paradigm. Profit is determined by the price a farmer receives for his crop. As discussed above, both conventional and organic wheat farmers sell to the FCI, and therefore receive the same price (i.e., MSP), diminishing farmer's incentive and enthusiasm for organic farming.

Soil Health, Yield, and Fertilization

The wheat yield per acre is a key factor in the profitability of a farming system. The yield in both conventional and organic farming is determined by the health of the soil, where soil health is defined as the ratio of current to optimal organic carbon. The notion of optimal soil health is complex and must be understood in the context of the soil type as well as the crops in question. However, an abstraction that helps illuminate the relevance of soil condition to crop yields in both conventional and organic farming is the level of organic carbon in the soil. Organic carbon is vital to soil's capacity to manage the nutrient cycles and nutrients (e.g., nitrate; phosphate; potash) that, together, determine the composite notion of soil health (Haney et. al., 2008).

When the soil is healthier, the yield is higher; conversely, when the soil lacks nutrients, biodiversity, and biomass, the environment is less conducive to crop growth and the yield is lower. Figure 3, below, shows how crop yields increase toward the maximum achievable yield as soil health increases.

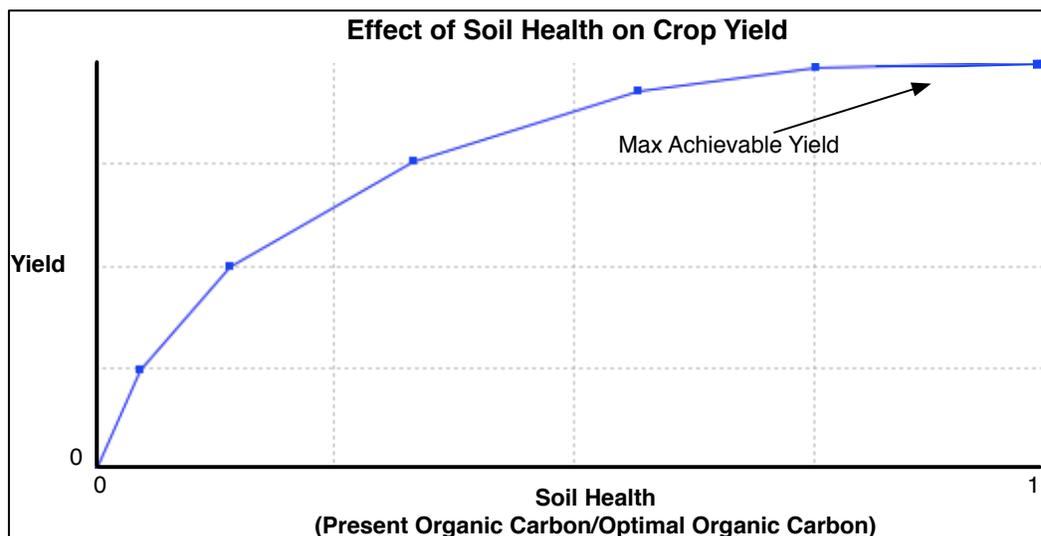


Figure 3: Effect of Soil Health on Crop Yield

In our model, soil health is represented as two stocks: **Soil Health Conventional** and **Soil Health Organic**. The value of the stock is the integration of the inflow, representing soil health development, minus the outflow, representing soil health degradation. To calculate the yield, a table function (Figure 3) is used to calculate the percent of the maximum yield that is achievable given the current state of the soil health. The equations for the Soil Health stocks are:

- **Soil Health Conventional** = INTEGRAL(Conventional Soil Health Development - Conventional Soil Health Degradation)
- **Soil Health Organic** = INTEGRAL(Organic Soil Health Development - Organic Soil Health Degradation)

In both farming systems, soil health is determined by a farmer’s fertilizer regimen: the amount of fertilizer applied relative to the amount of fertilizer required. Under optimal farming practices, farmers apply the correct amount of fertilizer to achieve maximum soil health, and therefore realize maximum yields.

Synthetic fertilizer used by conventional farmers in optimal quantities can increase plant growth and improve yields, thereby increasing profits (see reinforcing *Nutrient Fixation* loop in Figure 4, below). However, as synthetic fertilizer has near-immediate positive effects on plant growth that is visible in matter of days (Gomiero et al., 2011), and because farmers in India often lack knowledge of the complex relationship between fertilizer use and soil health, farmers often apply fertilizer in excessive quantities (IAASTD, 2008). Over time, excessive application of fertilizer degrades soil, causing soil pH to change and leaching essential nutrients away from plants. Such overuse evokes a reinforcing structure (see *Overapplication* loop in Figure 4), where excessive use of fertilizer decreases soil health, thereby decreasing yields, and ultimately causing farmers to apply even greater amount of fertilizer in the hope of recovering the lost yield. Such fertilizer overuse increases costs and reduces profits. Many farmers interviewed for this research reported having been trapped in the overapplication vicious cycle only after enduring losses over several years.

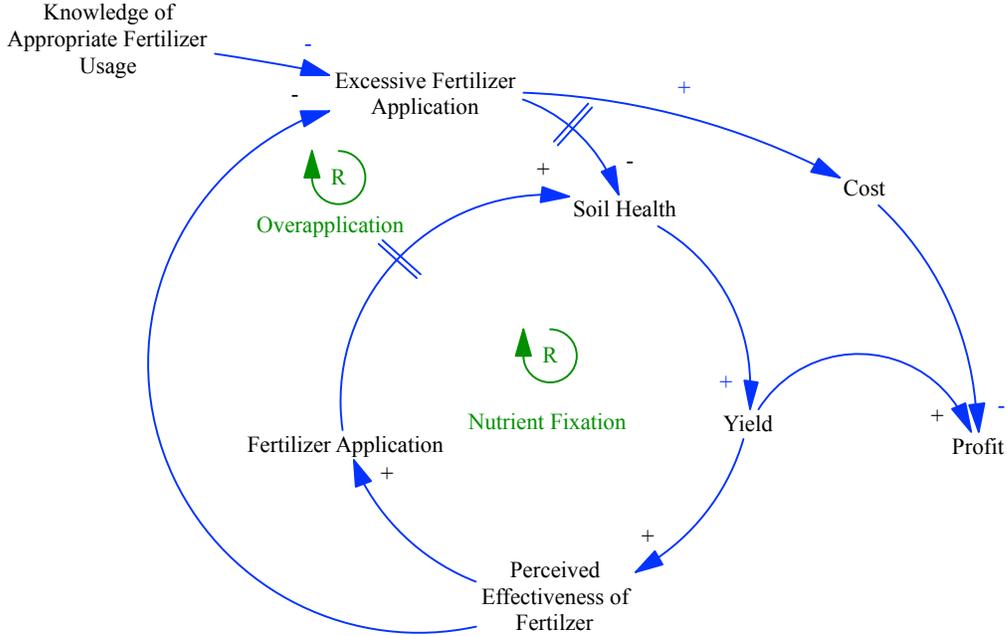


Figure 4: Effect of Fertilizer on SH and Yield

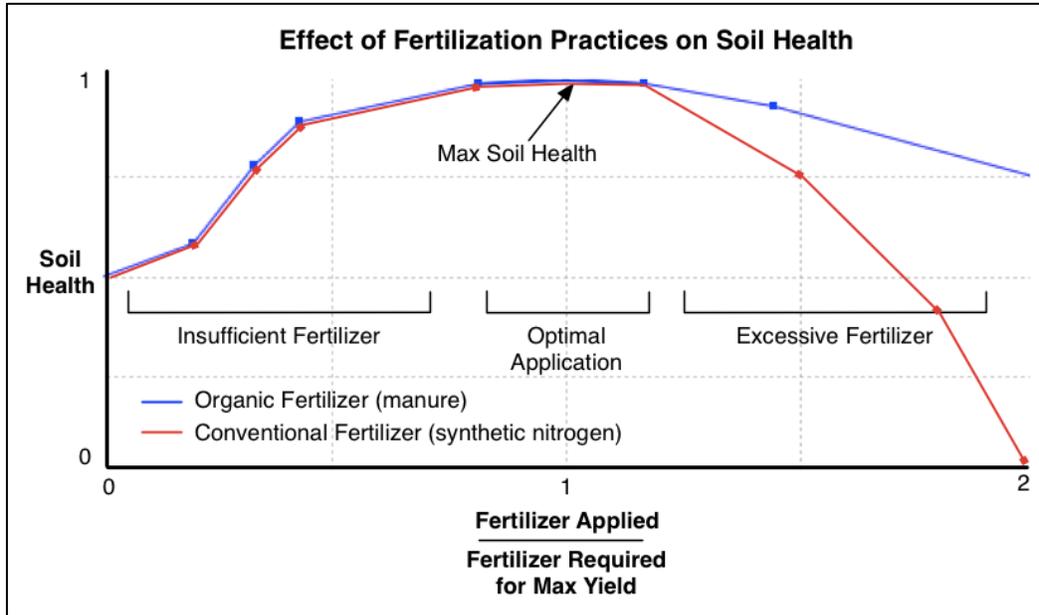


Figure 5: Effect of Fertilization Practices on Soil Health

In organic farming, manure availability is similarly a key factor. Farmers may not have sufficient livestock to produce adequate manure, or may need to use their manure for fuel rather than fertilizer. Though organic fertilizer develops soil health (shown in blue above), insufficient use of organic fertilizer will prevent soil from developing. A key distinction (not shown above but handled through model parameterization) is in how the use of synthetic fertilizers and organic manure differ in their effect on soil health: while synthetic fertilizer adds readily available nitrogen and produces immediate, visible results, nutrients in organic fertilizer take time to break down and soil health development (and degradation) is therefore a more gradual process (Clark et al., 1998).

In our model, the effect of a farmer’s fertilize regimen is represented as Indicated Soil Health, calculated for each farming system using a table function (Figure 5). When a farmer transitions to organic from conventional, the soil is also transitioned, so the indicated organic soil health must account for the state of the soil health at the time of the transition (i.e., at the end of the conventional farming regime). The indicated soil health in a conventional system is determined only by the fertilizer regimen.

To determine soil health in our model, the indicated soil health value is compared against the current stock of soil health, and the soil health of the farm increases, decreases, or stays the same. If indicated soil health is better than current soil health, the stock of soil health accumulates via the inflow; conversely, if indicated soil health is less than current soil health, the soil health of the farm is degraded and the stock is reduced via the outflow. The relevant inflow and outflow equations are:

- **Conventional Soil Health Development** = IF THEN ELSE((Indicated Conventional Soil Health > Soil Health Conventional), (Indicated Conventional Soil Health - Soil Health Conventional)/Time for Conventional Soil to

- Develop, 0)
- **Organic Soil Health Development** = IF THEN ELSE((Indicated Organic Soil Health > Soil Health Organic),(Indicated Organic Soil Health - Soil Health Organic)/Time for Organic Soil to Develop, 0)
- **Conventional Soil Health Degradation** = IF THEN ELSE(MAX(0,Soil Health Conventional)>Indicated Conventional Soil Health,(Soil Health Conventional -Indicated Conventional Soil Health)/Time for Conventional Soil to Degrade,0)
- **Organic Soil Health Degradation** = IF THEN ELSE(MAX(0,Soil Health Organic)>Indicated Organic Soil Health,(Soil Health Organic-Indicated Organic Soil Health)/Time for Organic Soil to Degrade,0)

Attractiveness of Farming Systems

A farmer's willingness to adopt organic farming depends on how attractive organic farming is relative to conventional farming. Attractiveness is determined by both economic and behavioral factors (Figure 6).

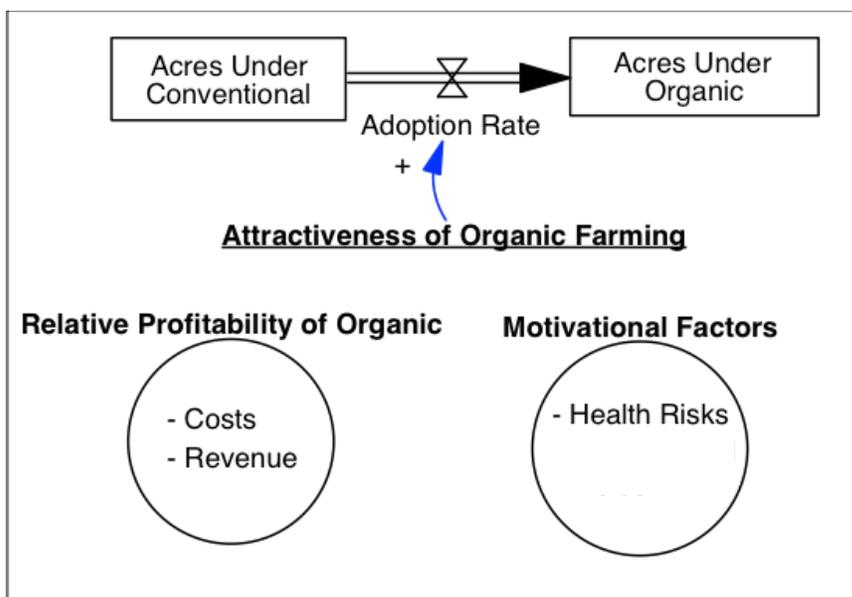


Figure 6: Factors Leading to Adoption of Organic Farming

As discussed above, a farm's profitability is determined by revenue (yield times price) and cost. Farmers may reduce costs by using inputs readily available on the farm (e.g., a well; children to work in the fields), while other farmers may have to purchase off-farm inputs. Though conventional farmers need to purchase fertilizer each year, in India the GOI subsidizes chemical farming, thereby reducing conventional farming costs, increasing profitability, increasing the attractiveness of conventional farming, and reducing the relative attractiveness of organic farming.

Similarly, farmers who own livestock may offset some cost of manure when doing organic farming (not shown in the causal loop diagrams).

Beyond economics, farmers may also become motivated to transition to organic practices for emotional reasons. For example, farming with synthetic inputs increases chemical exposure. Further, conventionally farmed foods have higher instances of pesticide residues and relatively lower nutrient contents than organically farmed crops (Barański et al., 2014). As farmers perceive an increase in these health risks for themselves and their families (e.g., when chemical use increases), their motivation to adopt organic practices also increases. In our field research, nearly every adopter of organic farming we interviewed was motivated to do so due to a case of cancer in their family or neighborhood that they correlated with the overuse of chemicals.

The number of acres that a farmer wants to transition from conventional to organic farming is represented as `Desired Organic Acres` in our model. The number of acres a farmer would like to place under organic production is determined by the attractiveness of organic farming relative to conventional farming, as well as the total acres on the farm.

$$\text{Desired Organic Acres} = \text{Rel Attractiveness of Organic} * \text{Total Acres}$$

As discussed above, the attractiveness of both conventional and organic farming (`Attractiveness of conventional` and `Attractiveness of organic`, respectively) is determined by economic factors and, in the case of organic, motivational factors. Though set to be equal at equilibrium in the current model, the weight, or importance, of economic versus motivational factors can be changed to reflect an individual farmer's decision-making paradigm. The relative attractiveness of organic, `Rel Attractiveness of Organic`, is therefore formulated as follows:

$$\text{Rel Attractiveness of Organic} = (\text{EXP}(\text{Attractiveness of organic}) / (\text{EXP}(\text{Attractiveness of organic}) + \text{EXP}(\text{Attractiveness of conventional})))$$

The above formulation uses a Logit function (Sterman, 2000), applied to `Attractiveness of organic` and `Attractiveness of conventional`, to determine the attractiveness of organic farming *relative* to the attractiveness of conventional farming.

Transition to Organic Farming

Once a farmer decides to adopt organic practices for a certain amount of his total farmland, the transition process begins. At any given time, all acres on the farm, represented as stocks in our model, must be either under conventional or organic practices. The organic adoption rate (`Organic Adop Rate`) determines the rate at which acres are converted from conventional farming to organic farming (i.e., flow out of the `Acres Under Conventional` stock and into the `Acres Under Organic` stock). The amount of acres to be transitioned is modeled as the gap between the desired amount of organic acres, `Desired Organic Acres`, and the current stock of organic acres. If such a gap exists, indicating that the farmer wants to move acres to organic, the gap is compared against the current stock of conventional acres. When the gap is smaller than the current acres in conventional, indicating that there are enough acres available to transition,

transition begins and the desired amount of acres are converted over the adjustment period. The formulation is therefore as follows:

$$\text{Organic Adop Rate} = (\text{MIN}(\text{Acres Under Conventional}, (\text{MAX}(0, \text{Desired Organic Acres} - \text{Acres Under Organic}))) / \text{Adjustment Time})$$

The MIN and MAX functions above enforce the assumption that acres cannot be moved back to conventional once they are transitioned to organic.

DYNAMIC MODEL AND PARAMETERIZATION

We now use the above formulations to present the dynamic model of transition to organic farming, and discuss model parameterization.

Dynamic Model

Considering the above, Figure 7, below, illustrates the stock and flow model that implements the dynamics and formulations described above. This dynamic model captures the physical, economic, and behavioral dynamics governing the transition from conventional to organic farming practices. The model represents a single *smallholder* farm, and a farmer's allocation of two acres to conventional or organic practices. As attractiveness of farming organically relative to farming conventionally increases, either due to economic or motivational factors, the farmer adopts organic practices for the desired percentage of land. The model currently does not allow land to be returned to conventional farming. Also, in order to focus on the transition, we currently do not make fertilizer use endogenous.

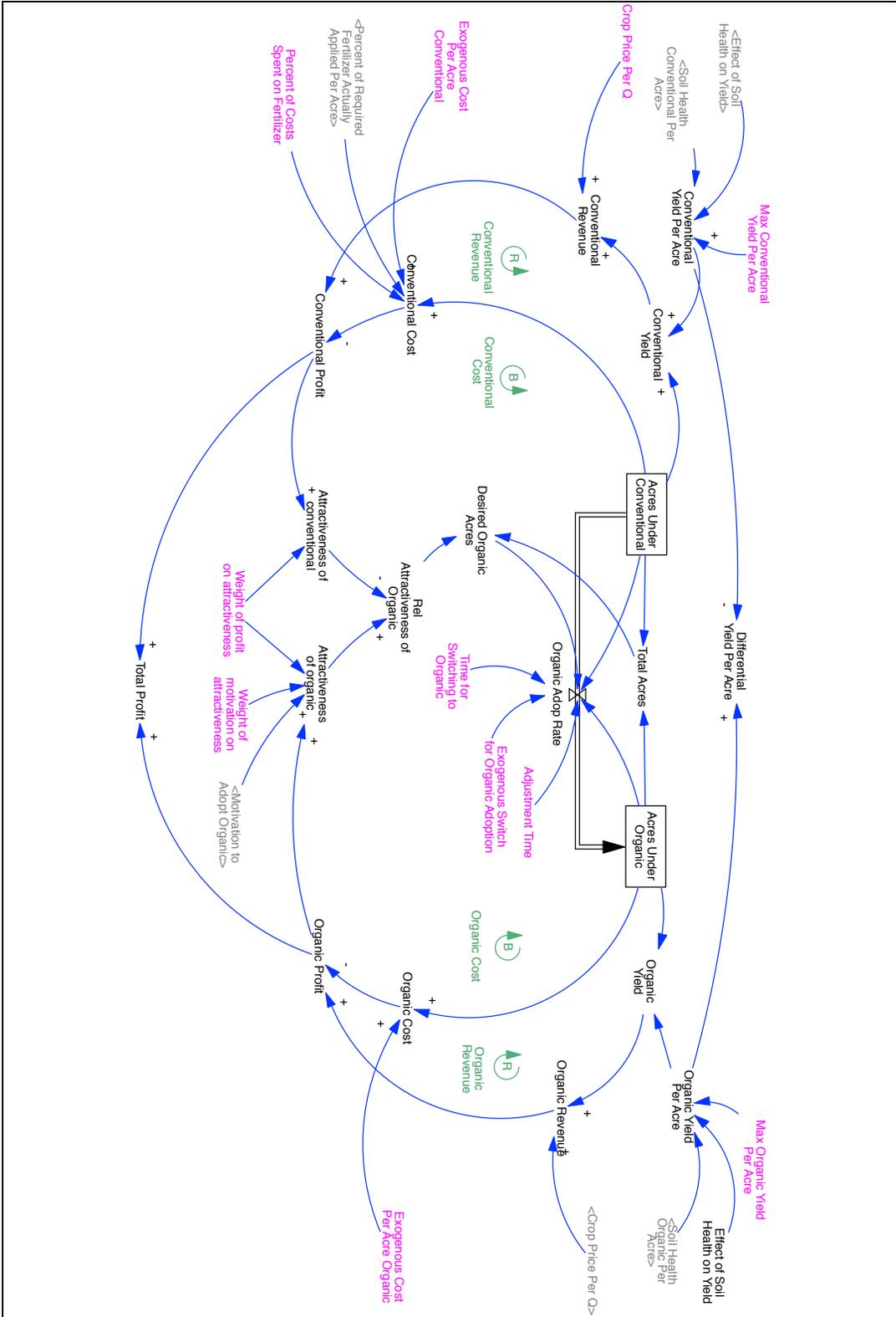


Figure 7: Dynamic Model of Adoption of Organic Farming

Model Parameterization

Table 1, below, shows the values used to initialize the model, and the associated rationale or source for each variable. Key control variables (e.g., exogenous switches) are discussed below.

- **Yield Potential:** the maximum yield achievable for a given farming paradigm is determined exogenously, and conventional and organic maximum yields can be set independently.
- **Cost Per Acre of Farming:** the cost per acre of farming under each system is determined exogenously and can be set independently. Both organic and conventional farming systems require additional inputs beyond fertilizer or manure, and needs for each farming system may be different.
- **Percent of Costs Spent on Fertilizer:** as a conventional farmer uses more (less) fertilizer, total costs increase (decrease). The model therefore allows for exogenous determination of the percent of total costs that a farmer spends on fertilizer.

Table 1: Model Parameterization

Model Parameter	Initial Value	Units	Rationale
Acres Under Organic	0	Acres	Most farmers start with conventional practices, and then shift to organic for economic or emotional reasons
Acres Under Conventional	2	Acres	1-2 acre is average farm size of wheat farms in Haryana
Adjustment Time	1	Years	Assume farmers only make decisions between seasons
Crop Price	600	Rs/Q	WheatBazar data for Haryana Range: 600-900Rs/Quintal
Max Conventional Yield Per Acre	40	Q/acre	WheatBazar data for Haryana Range: 40-50Q/acre
Max Organic Yield Per Acre	40	Q/acre	Range of 32- 60; 20% lower or higher than conventional
Exogenous Cost Per Acre Conventional	15000	Rs/acre	WheatBazar data for Haryana Range: 15,000-20,000
Exogenous Cost Per Acre Organic	15000	Rs/acre	WheatBazar data for Haryana

			Range: 15,000-20,000
Percent of Required Fertilizer Actually Applied Per Acre	1	Dmnl	Start with 100% optimal practices
Percent of Required Manure Actually Applied Per Acre	1	Dmnl	Start with 100% optimal practices
Percent of Costs Spent on Fertilizer	0.30	Dmnl	27 crops studied by Tej Pratap 2006 report fertilizer costs at 25-50% of the total costs with a mean value of 30%.
Soil Health Organic Per Acre	0	Dmnl	Soil health will accumulate according to initial fertilization.
Soil Health Conventional Per Acre	1	Dmnl	Perfect soil health due to optimal fertilization.
Time for Organic Soil to Develop	3	Years	3-4 years (Clark et al., 1998; personal conversations)
Time for Organic Soil to Degrade	3	Years	Assume same as development time
Time for Conventional Soil to Develop	1	Years	Time is < one year: assumption is that impact from chemical fertilizer is realized immediately
Time for Conventional Soil to Degrade	1	Years	Time is < one year: assumption is that impact from chemical fertilizer is realized immediately

ANALYSIS AND RESULTS

In this section, we perform model analysis in three stages. First, we demonstrate that the model is intendedly rational. Then, we present a base case where the dynamic model reproduces WBB behavior when switching from conventional to organic farming under the condition of excessive fertilization. Finally, we perform sensitivity analyses to study how various parameters affect the WBB Dynamics, namely: the level of over fertilization, the cost of organic manure, the efficiency of the package of practices used during conversion, and the rate at which the farmer switches to organic regime.

Intended Rationality

To demonstrate that the model behaves as intended, we present two cases: farming under effective conventional practices, and farming under excessive use of chemical

fertilizer. Appendix II offers the model parameterization to help the reader reproduce all of the runs presented in this section.

Effective Conventional Practices

When a farmer is applying the correct amount of chemical fertilizer relative to the amount required, soil health, and therefore yields and profits, is maximized. In this scenario, shown in Figure 8 below, organic farming isn't relatively more attractive and therefore the entire farm continues under conventional practices without switching to organic farming. The profit for the farmer, given parameterization in Table 1, in this case is Rs. 18,000 per year.

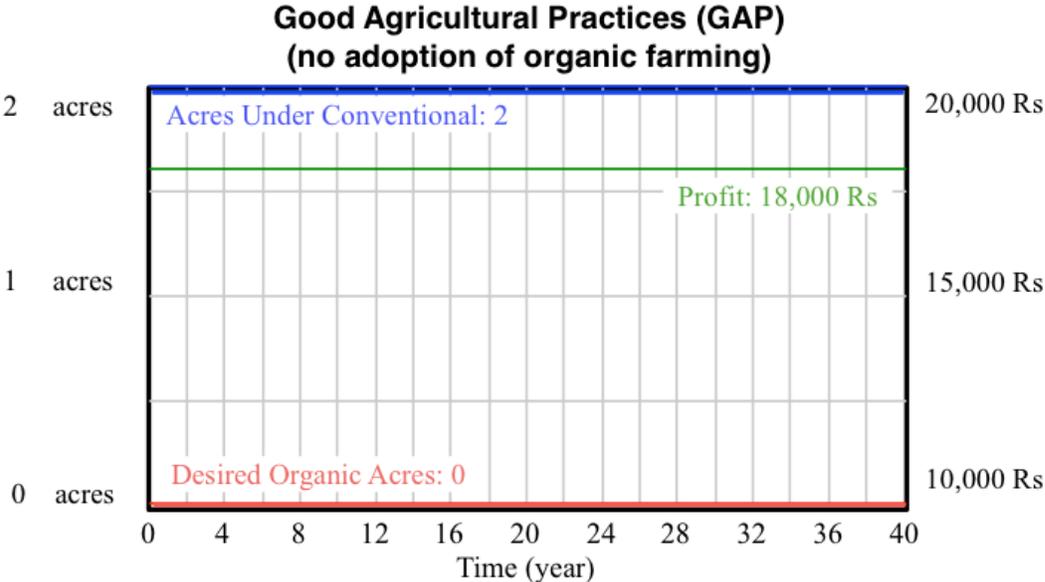


Figure 8: Dynamics of Good Agricultural Practices (GAP Farming)

Over Fertilization

Figure 9 and Figure 10, below, show model behavior under over fertilization. In this case, the farm begins under conventional farming with no fertilizer use until year 10, followed by a rise in Percent of Required Fertilizer Applied, a dimensionless quantity, from zero to two (i.e., 0-200%) between years 10-30, and then remaining at 200% for the rest of the run. In other words, each plot below can be viewed in two halves: under fertilization occurs when the fertilizer applied is below 1, and over fertilization occurs when above 1.

In Figure 9, we see the farmer switch from conventional to organic farming when over fertilization reaches nearly 180%. The binary choice formulation of the relative attractiveness of the two systems, discussed above, builds in certain hysteresis, which can be seen in the real world. As many factors affect agricultural productivity, farmers tend to wait and watch before deciding to switch.

Figure 10, presented right below Figure 9 for easier visualization of under and over fertilization scenarios, shows the behavior of yields and profits from two systems. At year 10, when the Percent of Required Fertilizer Applied begins to rise above

zero, farm productivity increases, and the Conventional Yield (in Quintal, Q), and hence the Conventional Profit (in rupees, Rs), rise until about year 14. After this point, yield (and hence revenue) saturates, even though the fertilizer application continues to rise (see years 14-24), whereas the profit plummets because of the rising cost of fertilizer. When very high amounts of fertilizer are applied, Conventional Yield also plummets, and the farmer switches to organic farming with proper application of manure.

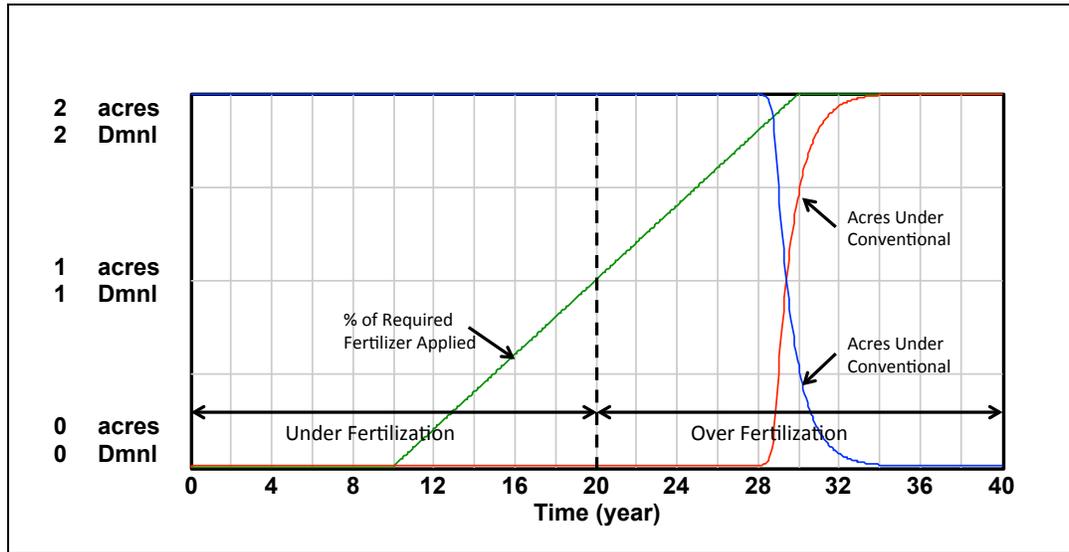


Figure 9: Over Fertilization and Switch to Organic Farming

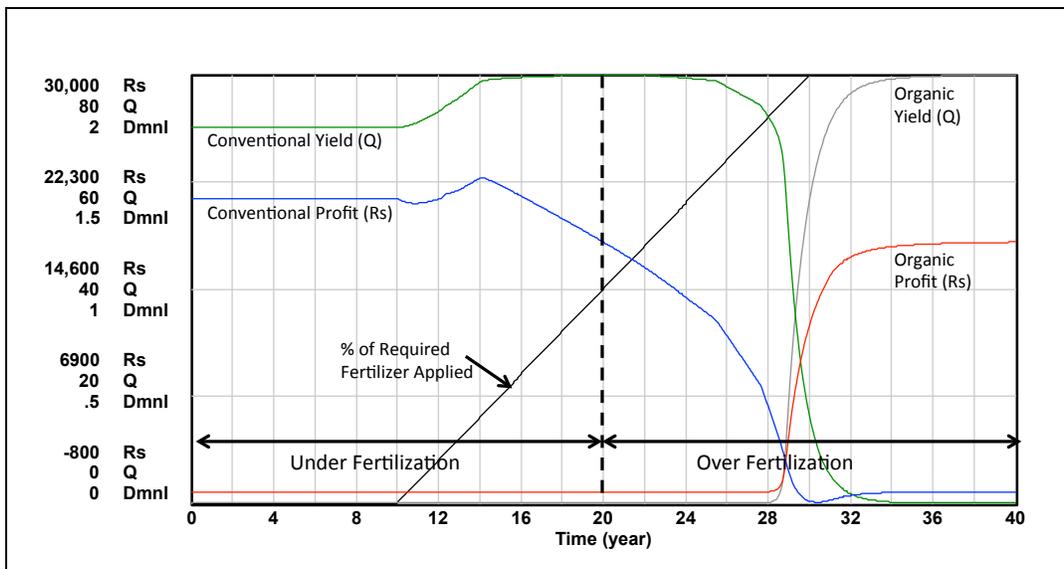


Figure 10: Over Fertilization, Yields and Profits

Base Run: Worse-Before-Better

One commonly cited situation in which organic farming becomes more attractive than conventional farming is when excessive amounts of chemical fertilizer have

been applied, degrading soil health and subsequently decreasing yields. We use this common condition to produce our base case. To produce this base case, we set the fertilizer use at a threshold⁵ beyond which the economics of organic farming become more attractive than those of conventional farming and a transition to organic occurs. The excessive use of fertilizer causes soil health to degrade, thereby causing conventional per acre yields to decrease. The transition is enabled by an exogenous switch at time ten to produce a more controlled condition that we will study under sensitivity in the following sections. The lower yields, combined with increased costs of fertilizer, cause profits to drop to a value of Rs. 3,600 (i.e., much smaller than the maximum possible profit of Rs. 18,000).

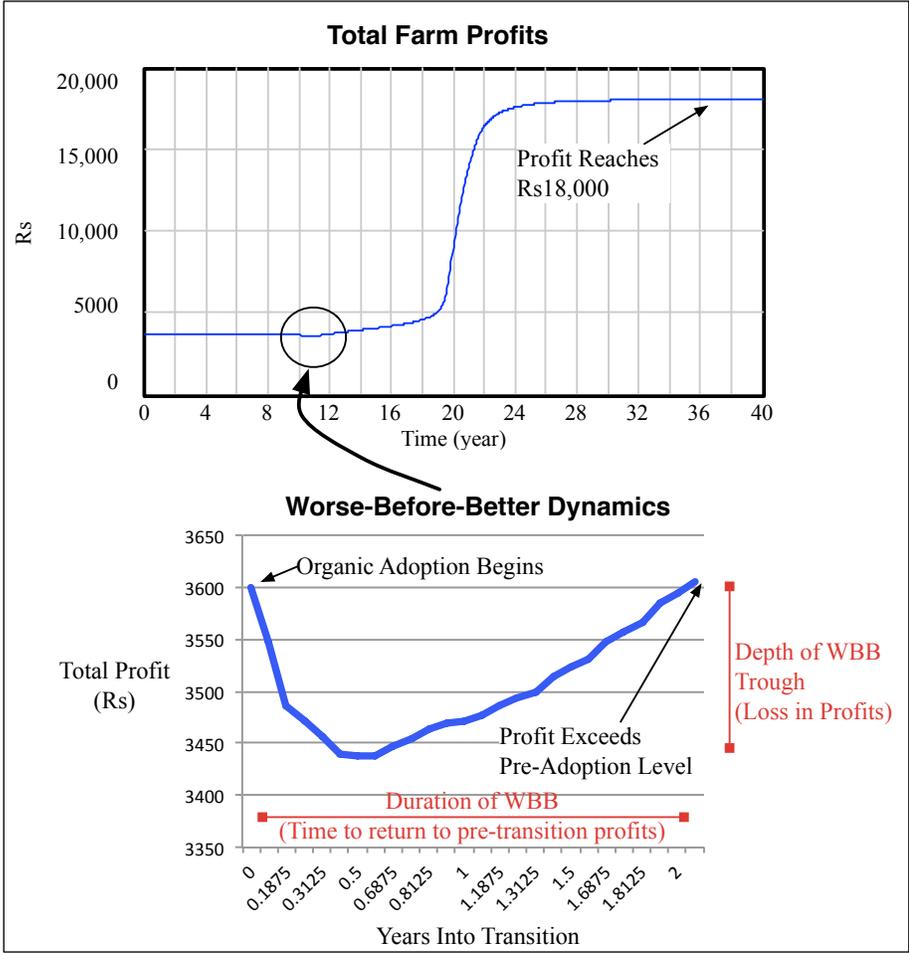


Figure 11: Before-Better Dynamics of Transition Due to Excessive Fertilizer Use

Figure 11, above, shows how excessive chemical use can trigger adoption of organic practices, and the associated worse-before-better dynamics (WBB) that

⁵ Current model calibration experiences this threshold when fertilizer use is 180% of required, and cost of fertilizer comprises 30% of total costs.

occur during the transition to organic farming. During the transition, WBB behavior occurs as initially soil health is degraded and yields suffer, and ultimately effective use of manure-based fertilizers restores soil health and increases yields. Over the first six months of the transition, profits decrease as it takes time for the application of manure to replenish the depleted organic carbon. However, as soil health recovers, the organic yield surpasses the previous conventional yield, the farmer no longer has to pay for inputs, and profits soon recover and, after two years reach Rs. 3,605, exceeding the pre-transition level. As soil health continues to develop and more land is moved into organic practices, profits continue to increase, eventually reaching Rs. 18,000.

Two parameters are of interest in studying the WBB Dynamics. First is “*Duration of WBB*,” the time it takes for Total Profit to equal or surpass its pre-adoption value. Second is “*Depth of WBB Trough*,” the difference between the pre-adoption value of Total Profit and the lowest value of Total Profit during the WBB phase. Both of these parameters determine the level and duration of economic losses that farmers must endure when transitioning to organic farming. Several factors affect these parameters and determine the severity of the WBB period. We will now study the impact of these factors on WBB dynamics.

Sensitivity Analysis: Impact of Parameters on WBB

Below, we discuss the sensitivity of WBB dynamics to four different conditions: degree of over fertilization prior to switching, cost of organic inputs, time to improve soil health, and the rate at which the farmer adopts organic farming.

Impact of the Level of Over Fertilization and Feasibility of Switching

Figure 12, below, shows how the level of over fertilization that a farmer has indulged in prior to switching to organic farming affects the duration and the depth of the WBB trough. This plot is produced by exogenously varying the percent of fertilizers applied relative to that required.

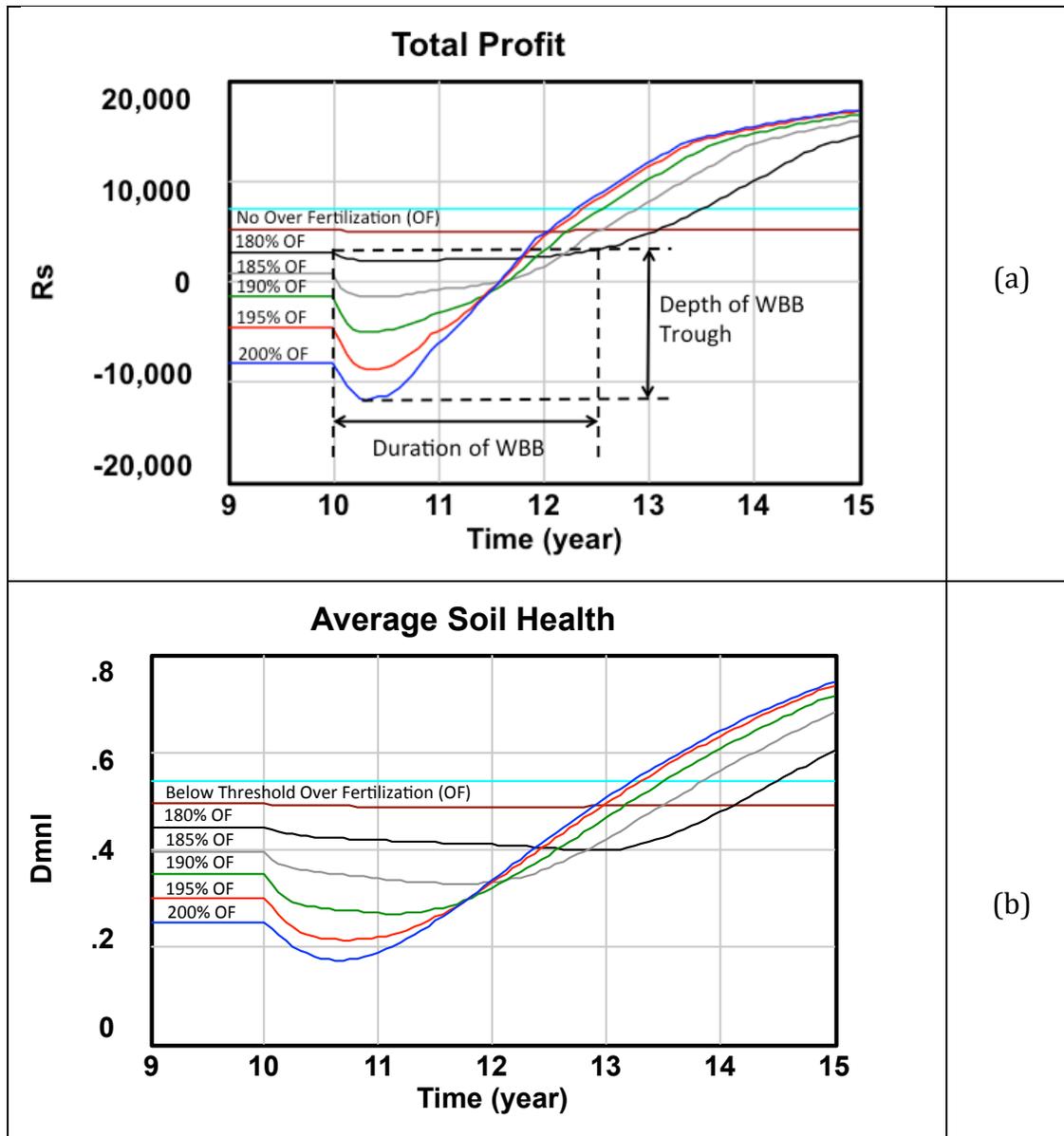


Figure 12 a, b: Impact of Excessive Chemical Fertilizer Usage on Profits and Soil Health during WBB

Figure 12(a) shows that the level of initial over fertilization has a profound impact on the viability of transitioning to organic farming for a smallholder farmer. First, excessive fertilization can turn farming into a losing proposition to begin with (i.e., negative Total Profit), and enduring a subsequent WBB transition would be further devastating for a smallholder farmer. This situation is not imaginary; it has been witnessed in cases where smallholder farmers get trapped in extreme indebtedness, and often consider ending their

lives.⁶ In such situations, short-term financial assistance is necessary for farmers to endure WBB dynamics. Conversely, we observe that it is best to transition to organic farming when soil health has not yet degraded severely (see 180% OF plot in Figure 12 a, b). Transitioning at such a juncture reduces the depth of trough, potentially making it affordable for a smallholder farmer. It also allows for sufficient time for the transition.

As such, the above insight is qualitative—meaning, it is not about the exact value of overfertilization as much as extreme vs. low levels of it. However, it is noteworthy that, unfortunately, such discussion about over fertilization and its impact on the feasibility of transition to organic farming is absent in the existing literature.

Impact of Organic Costs

There are a number of factors that influence the characteristics of the WBB transition under excessive chemical use. The base scenario described above assumes that the cost of organic farming is the same as that of conventional farming (i.e., Rs. 15,000 minus the cost of excessive fertilizer). However, organic farmers may experience higher costs, for example from increased labor requirements for weed and pest management (FAO, 2002; Foster et al., 2006), or because purchase of off-farm manure is necessary. In contrast, the cost of organic farming may be lower, for example in cases where on-farm labor and manure are available or when water requirements are reduced as soil health develops (IAASTD, 2008). Figure 13, below, shows the WBB dynamics under changes to organic costs (i.e., 10% and 20% cost increases and decreases).

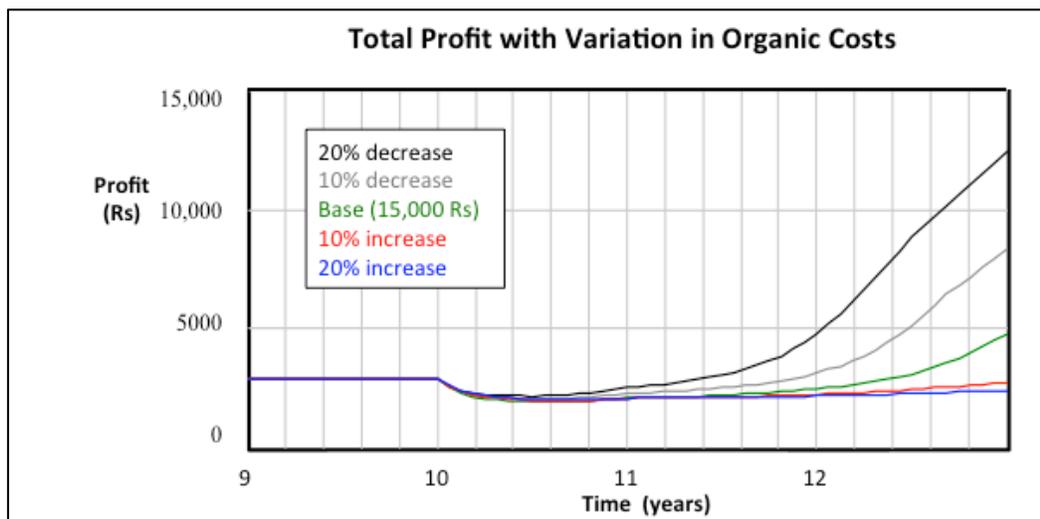


Figure 13: Changes to WBB Dynamics with Variation in Organic Costs

As the cost of organic farming increases, the duration of the WBB period increases significantly, and the depth of the WBB period increases slightly (Figure 13). Conversely, as

⁶ Unfortunately, farmer suicides in India have received much press (https://en.wikipedia.org/wiki/Farmers%27_suicides_in_India). While reasons behind this phenomenon are complex, low farm productivity due to excessive reliance on chemicals is certainly one of them.

costs decrease, the farmer experiences a shorter, slightly less severe drop in profits during the WBB period. For a smallholder farmer, understanding, and reducing, the costs associated with organic farming can increase the viability of transitioning to organic farming. Further, policies such as subsidies for organic inputs, or village-level infrastructure to support organic farming (i.e., organic manure production and distribution from cow shelters), could significantly improve farmer profits during transition to organic farming.

Impact of Time to Improve Soil Health (i.e., Efficiency of the Package of Practices)

The dynamics of the transition to organic farming also change depending on how long it takes the soil health to develop. Figure 14, below, shows the dynamics of the WBB period for soil health development times between one and five years.

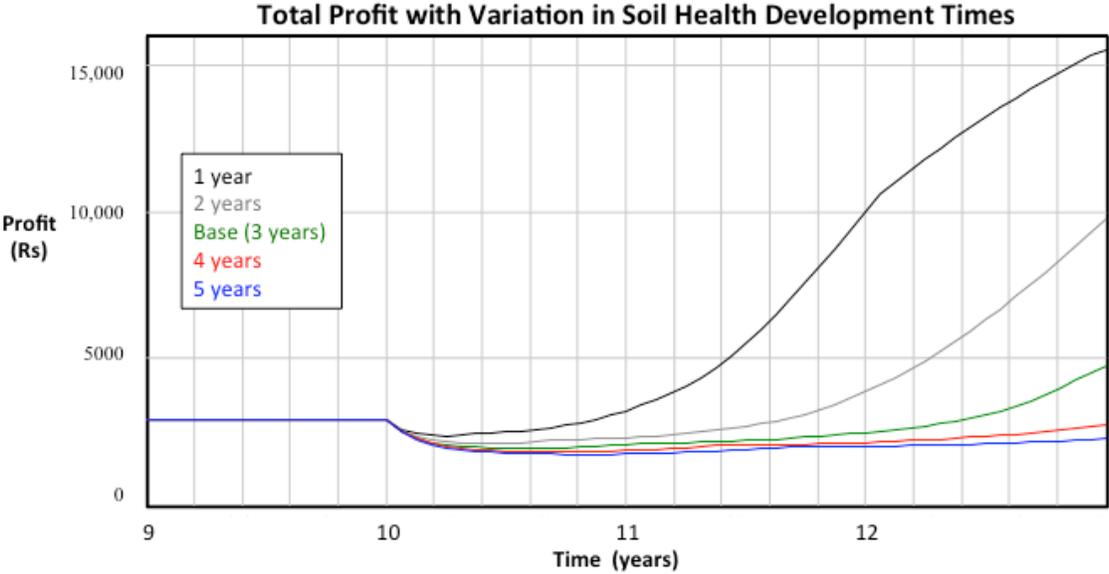


Figure 14: Changes to WBB with Variation in Soil Health Development Times

As the time for soil health to develop increases, the depth and duration of the WBB period increase, reducing farmer profits and decreasing the viability of transition to organic farming. There are many factors that influence the time necessary for soil health to develop under organic farming. The maximum achievable yield is not necessarily the same across organic and conventional practices, and further, achievable yield depends on the package of practice a farmer adopts and is capable of following through. For example, research indicates that the achievable performance (i.e., yield) of a farming system depends on the type and appropriateness of the seeds with respect to the farming context (Murphy et al., 2007)⁷. Further, the amount of manure applied relative to the amount needed will impact soil health development time. Farmers may not know how much manure they need to apply, or may not have sufficient manure available. Finally, variation in soil types (e.g.,

⁷ Under the current model calibration, a full transition to organic does not occur unless the max organic yield is within 9% of the max conventional yield. As only a partial transition occurs, a sensitivity analysis is not included, despite the presence of worse-before-better behavior.

across regions) and cropping patterns will impact the rate at which soil health develops. Additional research on soil health development times across organic farming conditions in India, as well as best practices for effectively communicating this information to smallholder farmers, is therefore necessary to create conditions under which soil health develops optimally, and farmers can experience less severe WBB periods.

Impact of Adoption Rate

The rate at which a farmer adopts organic practices also impacts the dynamics of the WBB period during transition. Figure 15, below, shows how faster adoption creates a deeper, but shorter, WBB period.

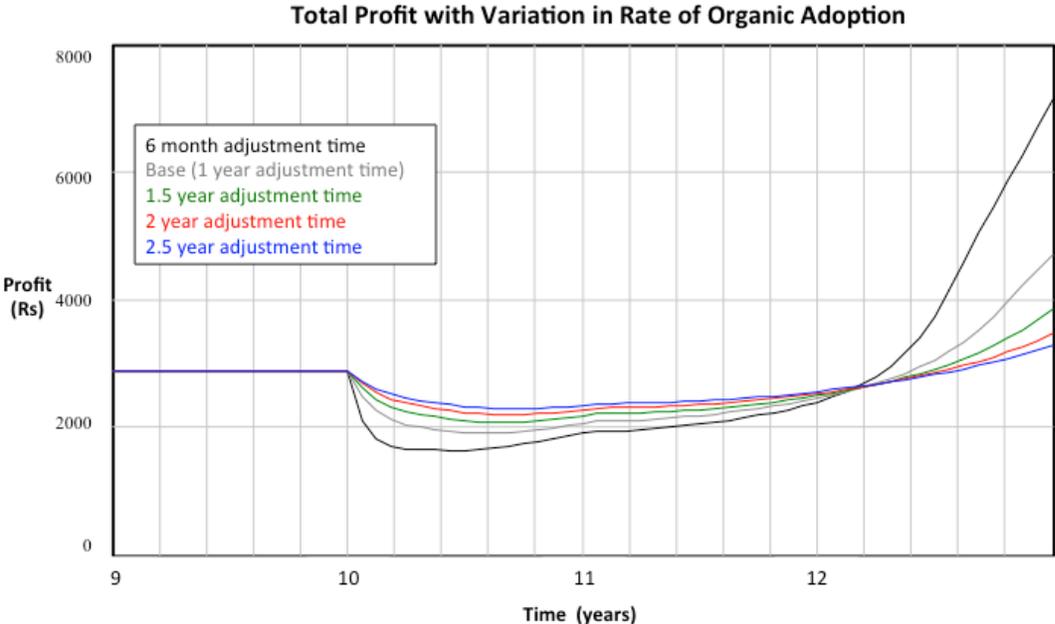


Figure 15: Effect of Adoption Rate on WBB

The depth of the drop in profits is determined by the amount of land that is initially transitioned. When the transition begins, the yield from the land in transition will fall, as it is no longer receiving synthetic fertilizer and has not yet had time to build soil health under organic practices. It may therefore be tempting for a farmer to leave some land under conventional practices, thereby lessening the steepness of the drop in income, and extending the total time of the transition. This extension may ultimately be detrimental, however, as it takes longer for the farm to return to the same levels of yield and therefore profits. This occurs because when the conventional land is ultimately transitioned, it will be in a worse (i.e., more degraded) condition, thereby increasing the time it takes to build soil health, increase yield, and achieve profitability. A farmer will therefore realize the maximum total yields more quickly if more acres are transitioned earlier. This makes sense, as soil health does not start to develop until land is placed under organic practices and manure is applied, thereby building organic carbon in the soil, and ultimately improving yields. This means that if a farmer can survive the short-term loss in profits, it is advantageous to initially, quickly, convert land to organic. Policies and training programs that help farmers understand these tradeoffs in context of their individual situations will

therefore have significant positive impact on a farmer’s ability to minimize WBB dynamics during transition.

Impact of Health-Based Transition on WBB

Farmers in India are increasingly concerned about the health risks introduced by excessive chemical fertilizer use. As chemical exposure increases and farmers attribute health problems to conventional farming practices, organic farming becomes more attractive. Field observations and interviews indicate that perceived health risks are often strong enough to motivate farmers to adopt organic practices. Figure 16, below, shows the transition to organic farming under high-levels of perceived health hazard. This plot looks very similar to the Adoption Rate Sensitivity plot above (Figure 15) with one notable difference: the total profit at the time of transition in the plots below is Rs. 18,000 (the maximum possible profit). In other words, in Figure 16, below, the transition to organic farming is purely due to motivational factors, not economics. However, the resulting economics of WBB are considerably different. When farmers perceive extreme health hazards and transitions to organic farming rapidly, the depth of trough, or the losses they incur, are large- nearly 50%. Yet, the total profits in this case are much higher than in all above cases, as farmers do not experience an initial drop in profitability due to excessive fertilizer use and the associated cost increases.

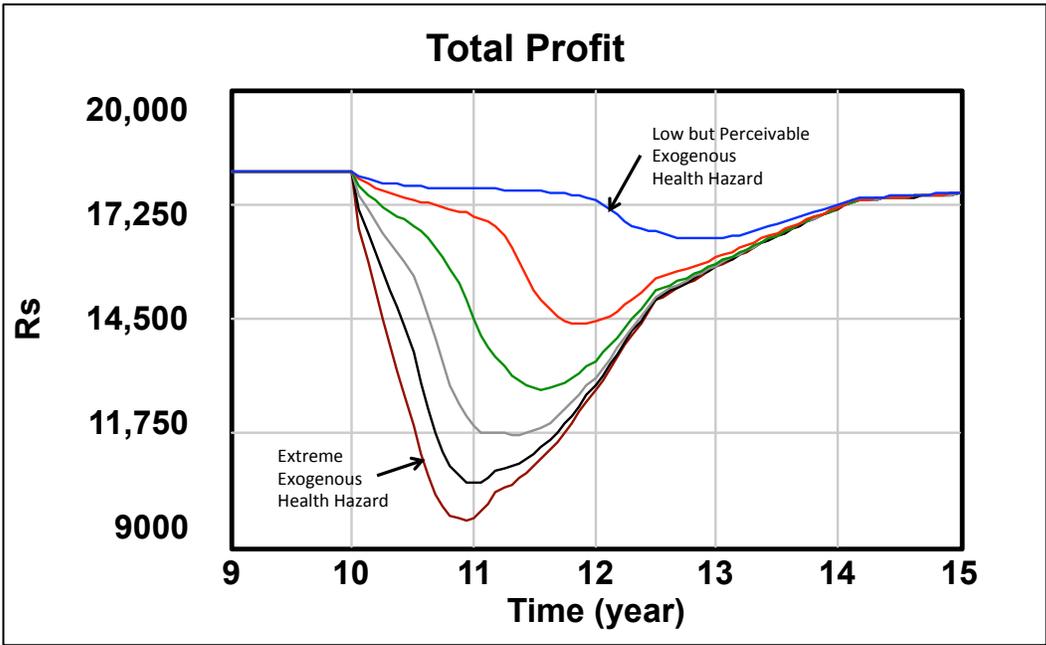


Figure 16: Transition to Organic Farming due to Perceived Health Risks

CONCLUSION

In this final section, we present a summary of the findings, as well as limitations and suggestions for further research and model expansion.

Summary and Implications

The dynamic model developed in the current effort demonstrates the necessary conditions for worse-before-better dynamics during transition from conventional to organic farming, as well as conditions under which transition is more viable. When a farmer uses excessive quantities of synthetic fertilizer, soil health degrades and both yield and total profit decrease. Once a threshold is reached, organic farming can become a more attractive option. If a farmer transitions to organic practices under these conditions, worse-before-better behavior will ensue. The viability of a transition to organic farming depends upon organic farming conditions and practices. Specifically, the per acre cost of organic farming, time for soil health to recover, and rate at which land is converted, can decrease or increase the duration and depth of the worse-before-better trough, as well as the profit level ultimately achievable. Figure 17, below, summarizes the results of the above sensitivity analyses in terms of both the duration (i.e., time to return to re-transition profitability, shown on the x-axis) and depth (i.e., loss in profits, shown on the y-axis) of the WBB period.

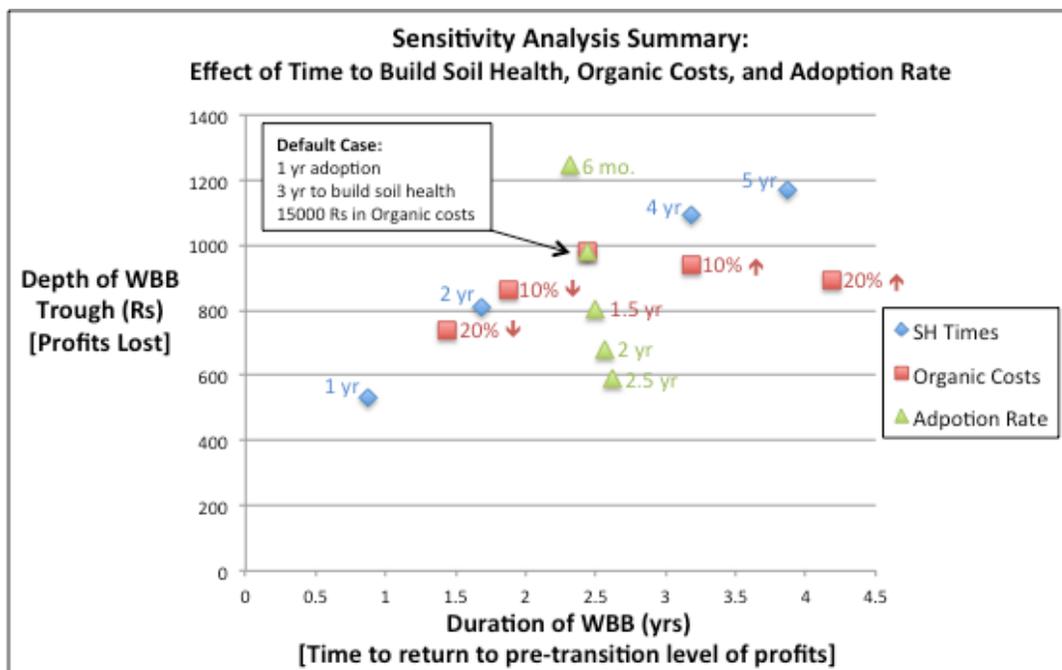


Figure 17: Effect of Soil Health Times, Organic Farming Costs, and Adoption Rate on WBB Depth and Duration

Decreasing soil health development time (blue diamonds, above), for example through effective application of farming practices and optimal selection of inputs, can reduce both the depth and duration of the WBB period. Similarly, decreasing the cost of organic farming (red squares, above), for example by using on-farm inputs such as byproducts of animal husbandry, can improve profitability during the WBB period. Finally, smallholder farmers can impact the depth and duration of the WBB period by controlling the rate at which they adopt organic practices (green triangles, above). The rate of adoption has a strong correlation with soil health development time: adopting organic practices slower than the rate at which soil health develops will increase the duration but decrease the depth, while a faster adoption will decrease the duration but increase the depth. The above dynamic

complexity suggests that policies and training programs that help farmers to not only understand these tradeoffs, but also create optimal transition conditions, are therefore necessary to enable farmers to transition to organic farming with minimized WBB dynamics.

Organic farming may also become attractive for non-economic reasons; however, a farmer's motivation must be sufficiently strong to induce adoption. Abrupt transition due to motivational factors can have significant losses (i.e., deeper WBB trough), but transitioning at an appropriately slow rate will keep overall profits higher. As such, voluntary transition due to motivational reasons is far better than that after delinquency from excessive fertilizer use. Excessive fertilizer use, a condition that happens frequently with smallholder farmers in India (IAASTD, 2008), is not only extremely detrimental to the environment and the health of farmers and their families (Yedla and Peddi, 2003; Amundson, 2015), but can also significantly exacerbate the loss of profits during transition to organic farming, or even make transition untenable. It is therefore important to educate farmers about the crucial importance of following optimal fertilizer regimens in order to maximize both profitability and health.

Overall, this research observes that, while organic farming promises environmental and health benefits, easing the adoption of organic practices requires understanding and systematically managing the economics of the transition (i.e., the WBB scenario). In India, farmer behavior may be influenced by numerous context-dependent factors; however, in the end a single farmer ultimately decides how to allocate his land along the spectrum of available agricultural practices-- a decision that, collectively, has a global environmental impact. Consequently, conditions must be created for them to perceive the transition to organic farming economically attractive and viable. Currently, the economics of worse-before-better scenario are unfavorable for transition to organic farming under the conditions of excessive fertilization, inadequate package of practices, and miscalculated rates of adoption. Understanding these factors and devising policies to manage them is necessary to enable individual farmers to mitigate the risk of transitioning to organic farming. Our effort in this research take a step in the direction of assisting policymakers and NGOs in enabling smallholder farmers to transition to more sustainable and profitable agriculture.

Limitations and Next Steps

The current model, while useful, can be improved to overcome its limitations. Future work is necessary to refine and expand the dynamic model, including:

- **Use a three-stock aging chain** to explicitly differentiate acres in transition and the soil health dynamics associated with transition. Using three stocks will represent both the physical dynamics-- that soil in transition is still recovering from chemical practices, while soil under organic practices has developed soil health-- and perceptions such as farmer and certification distinctions between organic production and land in transition.
- **Allow conversion back to organic** to capture conditions under which, and effects of, farmers abandoning organic practices.

- **Incorporate additional management techniques.** For example, the combined use of synthetic fertilizer and manure has been shown to be more effective than either treatment alone (Bajpai et al., 2006; Singhal et al., 2012). Similarly, tilling, cover cropping and intercropping practices change soil health dynamics and costs. Additional data collection on the ranges of variable and fixed costs and management practices is necessary, as costs associated with both conventional and organic farming also depend on the farming context and practices (Nemes, 2009).
- **Represent multiple seasons,** as farmers plant more than one crop per year (e.g., wheat and cotton rotation), and complementary crop combinations can complement each other to enhance soil health (e.g., legumes fixing nitrogen).
- **Move beyond yield per acre of a single crop,** as total productivity is a more accurate metric for determining profitability in organic systems (Seufert, 2012).
- **Include a learning curve structure** to capture how a farmer can reduce costs as experience accumulates (Sternan, 2000).
- **Explicitly model market dynamics for organic products.** Local buyers may be willing to pay price premiums for organic products as they develop trust in the farmer's practices. Certification may also allow a farmer to sell organic products at a premium to institutional buyers.
- **Incorporate motivation for conventional farming,** including chemical company advertising and government subsidies for fertilizer and seeds. Debt dynamics, for example borrowing to cover the cost of synthetic inputs, should also be modeled.

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