THE ECONOMIC IMPACTS OF *TRICHODERMA* AND COCOPITH IN BANGLADESH, INDIA, & NEPAL

PREPARED BY THE VIRGINIA TECH OFFICE OF ECONOMIC DEVELOPMENT

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Introduction

Farmers lose about one-third of their crops to pests and diseases.[1] Many have used synthetic pesticides as the solution to this challenge. However, the over-reliance on synthetic chemicals to protect crops and increase yields—a remnant of the 1960's Green Revolution—has resulted in negative environmental and health consequences and has in some cases lowered crop yields.[2] For this reason, Integrated Pest Management (IPM), which includes many non-chemical pest and disease control techniques, has been a growing approach to farming since the 1970s.[3]

Integrated Pest Management dates back to the end of the 19th century.[4] The Food and Agriculture Organization (FAO) of the United Nations defines IPM as:

> *"the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."*[5]

Biological interventions are considered a safer alternative to synthetic pesticides, however, changing the cultural norms to convince farmers that biological interventions can be effective is an ongoing challenge.

For 25 years, Virginia Tech's IPM Innovation Lab (IPM IL) program has promoted different packages of agricultural technologies meant to replace or complement synthetic fertilizers and promote the overall well-being of farmers and their families. *Trichoderma* and cocopith are two such technologies. *Trichoderma* is a naturally occurring fungus that helps support the root systems of plants, essentially serving as a natural immune booster by actively combating soil-borne diseases. The use of *Trichoderma* has long been included as part of the IPM package promoted by IPM IL. Note that this research focuses on *Trichoderma*'s use as a biocontrol method for diseases threatening vegetable crops; however, *Trichoderma* has many more applications outside of crop production including production of enzymes, antibiotics, metabolites, and biofuel. Cocopith is the dust present within coconut husks that, when used as

[1] Nakkeeran, S., Renukadevi, P., & K. E. A. Aiyanathan. (2016). Exploring the Potential of *Trichoderma* for the Management of Seed and Soil-Borne Diseases of Crops. In *Integrated Pest Management of Tropical Vegetable Crops* (pp. 77-130). Springer, Dordrecht.
[2] Sharma, P., Sharma, M., Raja, M., & V. Shanmugam. (2014). Status of *Trichoderma* research in India: A review. *Indian Phytopathol*, *67*(1), 1-19.
[3] Ibid.
[4] Kogan, M. (1998). Integrated pest management: historical perspectives and contemporary developments. *Annual review of entomology*, *43*(1), 243-270.
[5] AGP-Integrated Pest Management. *Food and Agriculture Organization of the United Nations.* Retrieved from: http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/

a growing medium, helps seedlings become stronger, more resilient adult plants. IPM IL has promoted this technology and considers it beneficial and complementary to *Trichoderma*.

While several studies conducted through IPM IL and other institutions examined the impacts of these two technologies on individual farmers, less research has addressed the broader benefits to industries associated with *Trichoderma* and cocopith. In collaboration with IPM IL, the Virginia Tech Office of Economic Development (OED) examined the social and economic effects of these two technologies on *Trichoderma* and cocopith supply chain industries in three Asian countries: Bangladesh, India (Tamil Nadu), and Nepal. OED conducted this comparative case study analysis to better understand how industries adopt and develop around these technological innovations, the factors supporting and inhibiting adoption, and the subsequent benefits taking place along the industry supply chain. This report includes a synopsis of existing literature, the methods used in this research, an examination of the *Trichoderma* and cocopith supply chains for each country and respective impacts, and an analysis of drivers supporting industry growth using Michael Porter's diamond model framework. The report concludes with recommendations for supporting future expansion and subsequent impacts of these two technologies.

Background Literature

To understand the social and economic effects of *Trichoderma* and cocopith in the aforementioned countries, it is important first to understand the factors that promote or limit the adoption of the technologies and the characteristics of the technologies themselves including scientific research on the effectiveness in lab and file settings.

Factors in adoption

The effects of a technology on one or more industries is highly dependent on adoption rates of said technology. The Everett Rogers' diffusion of innovations theory posits that the following characteristics of innovations play a role in whether a certain technology is adopted.[6]

- *Relative advantage*: if benefits of adoption outweigh the cost. For example, Nakkeeran et al. (2016) argue that biopesticides are safer for people and can be cheaper than their chemical counterparts.[7]

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[6] Rogers, E. M. (1962). Diffusion of InnovationsThe Free Press of Glencoe. *New York*.
[7] Nakkeeran, S., Renukadevi, P., & K. E. A. Aiyanathan. (2016). Exploring the Potential of Trichoderma for the Management of Seed and Soil-Borne Diseases of Crops. In Integrated Pest Management of Tropical Vegetable Crops (pp. 77-130). Springer, Dordrecht.

- *Compatibility*: if the technology is easy to use and socially accepted. For instance, farmers are used to spraying pesticides and may be more willing to adopt if the biological pesticide comes in similar spray form.
- *Complexity*: how easily adopters understand the new technology.
- *Observability*: if the benefits from the technology are easily visible from field trials or from peer usage. Additionally, trust plays a role as to whether farmers adopt.[8]

These characteristics affect whether farmers are innovators, early adopters, early majority adopters, late majority adopters, and finally, very late adopters. Stern (2018) notes that diffusion research has demonstrated that adopters at different phases are likely to trust different types of communicators.[9] For example, when an innovation, such as *Trichoderma*, is in its early stages, adopters are more likely to trust expert opinions whereas late adopters are most persuaded by colleagues and friends.[10] Stern (2018) also notes that early adopters tend to be more educated than late adopters, more active in their communities, and typically of a higher class in society.[11] The process of adopting a new innovation can take a long time, which should be considered throughout this research.

In this respect, *Trichoderma* and cocopith are relatively new technologies that are still in the earlier stages of adoption. Indeed, several studies have attributed the infancy of *Trichoderma* as a common biocontrol agent to low adoption rates, for instance, a 1-2% adoption rate in Bangladesh.[12] This is an issue of *complexity* in that most farmers do not yet understand the technology or its effective use.[13] Further complicating the issue are the different strains of *Trichoderma* that may be more or less effective depending on the region, soil, and soil-borne pathogens.[14] Similarly, cocopith adoption may be stymied if farmers apply raw cocopith, which can actually harm plants if not processed correctly, and think the

[8] Stern, M. J. (2018). *Social Science Theory for Environmental Sustainability: A Practical Guide*. Oxford University Press.
[9] Ibid.
[10] Ibid.
[11] Ibid
[12] Jackson, S.B. (2017). Adoption and Impacts of Integrated Pest Management for Cambodian Rice Farmers (Virginia Tech Master's Thesis) Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/80412; McCarthy, E.T. (2015). Analyzing the Impacts of an IPM Vegetable Technology Transfer in Bangladesh. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/56608.
[13] Hasan, S.M.M. (2017). Factors Affecting Pest Management (IPM) Adoption and Pesticide Use in Kenyan Vegetable Farmers. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/78826; McCarthy, 2015.
[14] Nakkeeran, S., Renukadevi, P., & K. E. A. Aiyanathan. (2016). Exploring the Potential of *Trichoderma* for the Management of Seed and Soil-Borne Diseases of Crops. In *Integrated Pest Management of Tropical Vegetable Crops* (pp. 77-130). Springer, Dordrecht; Sharma, P., Sharma, M., Raja, M., & V. Shanmugam. (2014). Status of *Trichoderma* research in India: A review. *Indian Phytopathol*, *67*(1), 1-19.

technology does not work as a result.[15] Overall, research has shown that adoption is easier if farmers are closer to support organizations, have more experience in agriculture, know other adopters, and attend training events.[16]

As newer technologies, *Trichoderma* and cocopith also have supply chain and institutional challenges that prevent quick adoption. Manufacturers, for instance, are still testing best ways to produce *Trichoderma* at commercial scale and are dealing with challenges such as quality control, shelf life, and tailoring strains to different regions.[17] In contrast, cocopith is ubiquitous in tropical countries and is cheap to manufacture, largely because it is a by-product. Since researchers discovered more uses for cocopith, the processing of cocopith has become a burgeoning industry in the last 20 years, with still room for growth.[18] With raw supplies of cocopith, the manufacturing industry could more than double its production, going from one million to 2.25 million tons, if adequate resources were met.[19] The largest producers of coconut palm trees are Indonesia, the Philippines, and India.[20] Harman (2000) also explains that barriers to the commercialization of *Trichoderma* could impede ubiquitous adoption of bio-control agents, specifically regarding institutional barriers and costs of registering such products.[21] While some companies have managed these institutional hurdles, others have struggled with registration of these products and other related barriers, thereby lowering the potential for widespread supply across regions.

Trichoderma: application and effectiveness

In a variety of crops,[22] *Trichoderma* controls the growth of soil-borne fungal diseases by first attacking the fungi that feed off plant roots and then extracting the nutrients from the fungal disease.[23] Two of the

[15] Coir Board, 2016. Coir Pith Wealth from Waste a reference. India International Coir Fair 2016, Coimbatore. Retrieved from: http://coirboard.gov.in/wp-content/uploads/2016/07/Coir-Pith.pdf.
[16] Hasan, S.M.M. (2017). Factors Affecting Pest Management (IPM) Adoption and Pesticide Use in Kenyan Vegetable Farmers. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/78826; McCarthy, E.T. (2015). Analyzing the Impacts of an IPM Vegetable Technology Transfer in Bangladesh. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/56608.
[17] Nakkeeran, S., Renukadevi, P., & K. E. A. Aiyanathan. (2016). Exploring the Potential of *Trichoderma* for the Management of Seed and Soil-Borne Diseases of Crops. In *Integrated Pest Management of Tropical Vegetable Crops* (pp. 77-130). Springer, Dordrecht.
[18] Coir Board, 2016. Coir Pith Wealth from Waste a reference. India International Coir Fair 2016, Coimbatore. Retrieved from: http://coirboard.gov.in/wp-content/uploads/2016/07/Coir-Pith.pdf.
[19] Ibid
[20] Duggan-Jones, D. I., Nichols, M. A., & Woolley, D. J. (2012, May). Effect of physical characteristics of coir on the productivity of greenhouse tomatoes. In *International Symposium on Soilless Cultivation 1004* (pp. 101-106).
[21] Harman, G. E. (2000). Myths and dogmas of biocontrol changes in perceptions derived from research on *Trichoderma* harzianum T-22. *Plant disease*, *84*(4), 377-393.
[22] Jackson, S.B. (2017). Adoption and Impacts of Integrated Pest Management for Cambodian Rice Farmers (Virginia Tech Master's Thesis) Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/80412
[23] Harman, n.d. *Trichoderma* spp., including T. harzianum, T. viride, T. koningii, T. hamatum and other spp. Deuteromycetes, Moniliales (asexual classification system). Cornell University College of Agriculture and Life Sciences. Retrieved from:https://biocontrol.entomology.cornell.edu/pathogens/*Trichoderma*.php; IPM IL, n.d.

most popular strains are *T. harzianum* and *T. viride*. Farmers use *Trichoderma* alone or in conjunction with other biocontrol mixes to reduce disease, stimulate plant growth, enhance stress resistance, and accelerate composting.[24] For example, farmers often complement *Trichoderma* application with *Pseudomonas fluorescens*, which has similar effects on bacterial pathogens.[25] Moreover, farmers can use *Trichoderma* in a number of ways to promote the viability of their crops. While multiple forms of *Trichoderma* exist (see Table 1), the most distributed and researched form of *Trichoderma* comes in a talc powder formulation.

Table 1. *Trichoderma application types*[26]

Trichoderma application	Description	Country
Basal application/soil treatment, often using talc powder formula	*Trichoderma* is applied directly to the soil or composted (sometimes with cocopith) prior to planting seeds or seedlings. In Bangladesh, farmers create a "Tricho-compost," typically consisting of cow manure, molasses, maize bran, sawdust, poultry refuse, water hyacinth, ash, and *Trichoderma harzianum*. The compost decomposes for 35-50 days and then dries out in the sun before application to fields.	Bangladesh, Nepal, India
Seed treatment	Seeds are dipped into *Trichoderma* (powder or liquid) prior to planting.	Bangladesh, Nepal
Foliar spray	*Trichoderma* powder or liquid (commercially available) is mixed with water and used to spray the foliage of the plant. Tricho-leachate is a byproduct of Tricho-compost. It is mixed with water and applied as a foliar spray by farmers.	Bangladesh, India, Nepal
Drip Irrigation	*Trichoderma* can be mixed into a drip irrigation system.	India, Nepal

Trichoderma is effective in preventing the diseases for a variety of horticultural products. Diseases shown to be reduced through the use of *Trichoderma* include: seedborne and soil-borne pathogens (fungal,

Trichoderma, the fighting fungus. Virginia Tech IPM Innovation Lab. Retrieved from: https://ipmil.cired.vt.edu/success-and-impact/success-stories/*Trichoderma*/.

[24] Harman G.E. 2000. Myths and dogmas of biocontrol changes in perceptions derived on Trichoderma harzianum T-22. Plant Dis. 84 (4): 377−393; Błaszczyk, L., Siwulski, M., Sobieralski, K., Lisiecka, J., & Jędryczka, M. (2014). Trichoderma spp.–application and prospects for use in organic farming and industry. *Journal of plant protection research*, *54*(4), 309-317.

[25] Nakkeeran, S., Renukadevi, P., & K. E. A. Aiyanathan. (2016). Exploring the Potential of *Trichoderma* for the Management of Seed and Soil-Borne Diseases of Crops. In *Integrated Pest Management of Tropical Vegetable Crops* (pp. 77-130). Springer, Dordrecht.

[26] Harris, L.M. (2011). Modeling a Cost- Effective IPM Dissemination Strategy for Vegetables and Rice: An Example in South Asia (Virginia Tech Master's Thesis) Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/33404; McCarthy, E.T. (2015). Analyzing the Impacts of an IPM Vegetable Technology Transfer in Bangladesh. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/56608.

nematode, and viral), sheath blight, leaf spots, wilts, red rot, smut, rust and leaf spots, spot blotch, early blight, late blight, black scurf, and root knot nematode.[27] In turn, *Trichoderma* may increase vegetable crop yields.[28] Working with cabbage in the lab, Nahar et al. (2012) found that both *Tricho*-compost and the *Tricho*-leachate (the liquid that runs off from the compost) help germination rates, plant growth, as well as plant vigor, and subsequently reduces seedling mortality caused by *Rhizoctonia*, *Sclerotium* and *Fusarium* species.[29] Additionally, Muniappan et al. (2010) reported field trials using *Tricho*-compost on tomato crops and saw increases in tomato yields by 16.4% to 25.3%.[30] In a field trial of shallots, Muniappan et al. (2013) found that the plots with the highest yields of quality produce were those that involved the use of mosquito-nets and an application of *Trichoderma*, whereas the plots with the lowest quality were farmer practices which did not include *Trichoderma*.[31] Uddin et al. (2009) found that treating both the seed and the soil was most effective compared to single application, but evidence suggests that the application of *Trichoderma* does decrease the incidence of diseases and increases yields for a multitude of crops.[32]

Clearly, the effectiveness of *Trichoderma* on horticultural crops is evident from laboratory and field trials. However, the economic impacts of *Trichoderma* are difficult to discern. While surplus studies exist that assess the economic impacts of IPM packages that may include *Trichoderma*, no studies have isolated the biocontrol agent. Nor has any research examined the larger supply chain benefitting from *Trichoderma*'s slow but growing adoption.

Cocopith: application and effectiveness

Cocopith (sometimes called coconut dust, or coco peat in its decomposed form) comes from the husk of a coconut and was once considered a waste product of processing the husk fibers to make ropes, mats, and

[27] Birthal, P. S., & Sharma, O. P. (2004). Integrated pest management in Indian agriculture; Muniappan, R., Vaughan, L., Rich, M., Ohland, M. & K. Mabry. (2010). Integrated Pest Management Collaborative Research Support Program FY 2010 Annual Report. Retrieved from: https://ipmil.cired.vt.edu/wp-content/uploads/2014/05/IPM-CRSP-Annual-Report_2009-2010.pdf
[28] McCarthy, E.T. (2015). Analyzing the Impacts of an IPM Vegetable Technology Transfer in Bangladesh. (Virginia Tech Master's Thesis). Retrieved from: https://vtechworks.lib.vt.edu/handle/10919/56608.
[29] Nahar, M. S., Rahman, M. A., Kibria, M. G., Karim, A. R., & Miller, S. A. (2012). Use of tricho-compost and tricho-leachate for management of soil-borne pathogens and production of healthy cabbage seedlings. *Bangladesh Journal of Agricultural Research*, *37*(4), 653-664.
[30] Muniappan, R., Vaughan, L., Rich, M., Ohland, M. & K. Mabry. (2010). Integrated Pest Management Collaborative Research Support Program FY 2010 Annual Report. Retrieved from: https://ipmil.cired.vt.edu/wp-content/uploads/2014/05/IPM-CRSP-Annual-Report_2009-2010.pdf
[31] Muniappan, R., Vaughan, L., Fayad, A., & Smith, M. (2013). IPM CRSP Annual FY 2012 Annual Report.
[32] Ibid.

other products.[33] Indeed, for every 10,000 coconut husks, a manufacturer could process approximately 1.6 tons of cocopith.[34]

Due to cocopith's lightweight cellulosic structure, the substance can be used as a growing medium to facilitate the root growth in seedlings.[35] This technology has a high water holding capacity, with high pore space, is low density, and has a slow decomposition rate.[36] Cocopith is also an effective growth medium for seedlings because it contains high microbial activity that reduces the incidence of disease among seedlings and may increase the plant's uptake of nutrients.[37] The director of Virginia Tech's IPM IL has explained that raising plants in coconut dust is more successful than soil-grown seedlings because soil carries bacterial and fungal diseases.[38] These properties have made cocopith a popular growth medium for seedlings, oftentimes in combination with other mediums and sometimes replacing certain mediums like soil and peat.

However, raw cocopith needs to be washed and processed prior to use before it is suitable for raising seedlings. In order to make processed cocopith, the raw substance needs to rest or mature for six months to lower the salt, tannin, and phenol and to allow it to reach a more neutral ph. This processing phase adjusts the initial carbon to nitrogen ratio, which can harm plants. Then, the pith is filtered to remove unwanted waste and finally is rinsed with quality water to reduce its salt content or electrical conductivity. Once the pith is dried, it is often packaged into bricks for transport. Before it can be used for agriculture, the cocopith needs to be composted. [39]

International demand for coir-based erosion control and the increased use of cocopith as a growth medium for seedlings has increased. Farmers and nurseries have benefited from this product, and there is a growing manufacturing industry invested in cocopith. The prices of cocopith have also increased as a result.[40] As of 2015, cocopith accounts for 50% of the coconut husk market and 5% of the coconut

[33] Bhatnagar, A., Vilar, V. J., Botelho, C. M., & R. A. Boaventura. (2010). Coconut-based biosorbents for water treatment—a review of the recent literature. *Advances in colloid and interface science*, *160*(1-2), 1-15.
[34] Coir Board, 2016. Coir Pith Wealth from Waste a reference. India International Coir Fair 2016, Coimbatore. Retrieved from: http://coirboard.gov.in/wp-content/uploads/2016/07/Coir-Pith.pdf.
[35] Rich, M. (2014, April 10). Seeding success in India turns coconut dust into gold. *Virginia Tech News.* Retrieved from: https://vtnews.vt.edu/articles/2014/04/041014-outreach-oiredseedlingsinindia.html
[36] Udayana, S.K., Naorem, A., & N. A. Singh. (2017). The Multipurpose Utilization of Coconut By-Products in Agriculture: Prospects and Concerns. *Int. J. Curr. Microbiol. App. Sci*, *6*(6), 1408-1415.
[37] Hyder, N., Sims, J. J., & Wegulo, S. N. (2009). In vitro suppression of soilborne plant pathogens by coir. *HortTechnology*, *19*(1), 96-100; Thomas, G. V., Palaniswami, C., Prabhu, S. R., Gopal, M., & Gupta, A. (2013). Co-composting of coconut coir pith with solid poultry manure. *Current Science*, 245-250.
[38] Rich, M. (2014, April 10). Seeding success in India turns coconut dust into gold. *Virginia Tech News.* Retrieved from: https://vtnews.vt.edu/articles/2014/04/041014-outreach-oiredseedlingsinindia.html
[39] Ibid.
[40] Coir Board, 2016. Coir Pith Wealth from Waste a reference. India International Coir Fair 2016, Coimbatore. Retrieved from: http://coirboard.gov.in/wp-content/uploads/2016/07/Coir-Pith.pdf.

product market.[41] This research examines the industry supporting cocopith's use in agricultural production, and explores barriers to adaptation and socio-economic impacts.

Conceptual Framework

When looking holistically at the social and economic impacts of cocopith and *Trichoderma* it is necessary to understand not just the supply chain relationships, but the factors that support or detract from the success of the industries. Michael Porter's Diamond Framework is useful for understanding how an industry functions and remains competitive within a particular country. In international contexts, the model is sometimes used to explain the factors contributing to the competitiveness of industry clusters as a whole, such as agriculture or textiles.[42][43][44] The model has also been used to explore more niche industries, such as Italian tile [45], French wine[46], Indian saffron[47], and Korean apparel.[48] Using this framework together with the comparative case study method provides new insight into factors unique or common between countries that affect the growth of the industries. These factors influence the competitiveness of *Trichoderma* and cocopith both locally and internationally, which in turn affects the subindustries throughout the supply chains, including farmers. This comparative analysis leads directly into recommendations for areas of change and improvement for future work with *Trichoderma,* cocopith, and related agricultural technologies. The model has four key elements: Factor Conditions; Demand Conditions; Related and Supporting Industries; and Firm Strategy, Structure, and Rivalry. While not included in the original model, Government is an additional node commonly seen by users of this framework, and in the case of Nepal and Bangladesh, is embedded within the discussion of Factor Conditions.

Factor Conditions: Factor conditions include the inputs used in production: human capital, monetary capital, infrastructure, natural resources, etc. In order for an industry to maintain competitiveness, it is

[41] Ethical Consumer. (2015, April). How sustainable is coir pith? Retrieved from: http://www.ethicalconsumer.org/ethicalreports/gardening/coirpith.aspx.
[42] Karácsony, P. (2008). Analysis of competitiveness of Hungarian wheat sector with Porter's Diamond Model. Journal of Central European Agriculture, 9(3), 399-403.
[43] Malkus, S. (2018). Dutch agricultural trade flows: An analysis using Porter's Diamond Model (Bachelor's Thesis). Wageningen Research University. Retrieved from: http://edepot.wur.nl/444274
[44] Vu, H. T., & Pham, L. C. (2016). A dynamic approach to assess international competitiveness of Vietnam's garment and textile industry. SpringerPlus, 5, 203. doi:10.1186/s40064-016-1912-3.
[45] Porter, M. E. (1993). The competitive advantage of nations (pp. 73-93). Cambridge: Harvard Business School Management Programs. https://hbr.org/1990/03/the-competitive-advantage-of-nations
[46] Porter, P. M., Takeuchi, H., Baibakova, M., Guilford, M., Lee, J., Sarafa, R., & Weigand, M. (2013). The French Wine Cluster. Harvard Business School.
[47] Aghdaie, S. F. A., Seidi, M., & Riasi, A. (2012). Identifying the barriers to iran's saffron export by using porter's diamond model. International journal of marketing studies, 4(5), 129.
[48] Jin, B., & Moon, H. C. (2006). The diamond approach to the competitiveness of Korea's apparel industry: Michael Porter and beyond. Journal of Fashion Marketing and Management: An International Journal, 10(2), 195-208.

necessary for these to be created and improved through investments. Substantial endowments in labor (population) and/or natural resources do not imply nations are more competitive in an industry, and consequently provide a disadvantage if nations rely on this to spur the industry (Porter, 1990).[49]

Demand Conditions: Demand conditions include both domestic and international markets for an industry. However, domestic demand can provide comparative advantages, as domestic buyers provide companies with an early interpretation of needs through early adoption. A nation with critical and knowledgeable domestic consumers will have a competitive advantage, as companies are compelled to innovate. Elements of Roger's Diffusion of Innovations framework are embedded within a discussion of demand conditions.

Related and Supporting Industries: This refers to the industries that are suppliers and purchasers of industry products. A robust supply chain and companies that add-value and/or use industry products will again lead to a nation to have a competitive advantage. In the case of Nepal and Bangladesh, the primary related and supporting industries are farmers, who are also the primary domestic buyers of *Trichoderma* and cocopith. Therefore, this section is omitted from those two case studies.

Firm Strategy, Structure, and Rivalry: Nations differ in culture and customs, and this holds constant across different business/industry organizations and management structures. Firm strategies include marketing, production, and visioning procedures companies use. Rivalry refers to domestic companies that compete in a specific industry. Competing domestic firms spur innovation as firms compete and try to gain a larger share of the domestic market.

Government: The role of government is not included in the original diamond model; however, Porter (1990) highlights government as critical in industries' competitive advantage, providing an ancillary role to amplify the system created by the four points of the model. Government roles are nuanced when supporting industry, and Porter (1990) states the most effective government will encourage and challenge industry to promote innovation.[50]

Methodology

After understanding the factors that contribute to adoption, the characteristics of the technologies, and the conceptual framework through which data can be analyzed, it is then critical to see the actualization of these concepts through primary data. Using primarily interviews and site visits, the research team

[49] Porter, M. E. (1990). The Competitive Advantage of Nations, London.
[50] Ibid

examined the supply chains surrounding the technologies as well as non-commercial institutional support systems including extension and government policy.

Data collection methods

The research began with an exploratory trip to Nepal and Tamil Nadu to meet with the scientists and extension personnel responsible for facilitating the adoption of *Trichoderma*. In Tamil Nadu, researchers met with senior and junior scientists, *Trichoderma* manufacturers, one nursery owner, and a coconut husk separation factory. In Nepal, researchers were hosted by iDE Nepal, the IPM IL in-country partner. They observed meetings with the iDE-IPM IL team, went on a site visit to a field trial demonstration area, and spoke with a women's group who recently started using *Trichoderma*. The information gathered from this exploratory trip informed the subsequent research design. At the request of the IPM IL Director, the research team added Bangladesh as an additional case study. Four months after the initial trip, the research team travelled again to India, Nepal, and Bangladesh for a series of semi-structured short interviews with members of the *Trichoderma* and cocopith supply chains, as well as tours of farms, manufacturing plants, and research facilities. In the case of Nepal and Bangladesh, members of the IPM IL team scheduled interviews ahead of the visits. For TNAU, a senior PhD candidate under the direction of a researcher from the Department of Agricultural and Applied Economics coordinated site visits and interviews. In the case of all three countries, OED researchers requested that the IPM IL team schedule interviews with agrochemical suppliers and manufacturers, nursery owners, government researchers, and cocopith importers and manufacturers. In the case of Bangladesh, the IPM IL team suggested we also speak with farmers. Most of the interviews were conducted in the native language of the interviewee, with translation done by an IPM IL team member. In many of the interviews, researchers also drew supply chain maps together with the interviewee. These interviews were audio recorded, and field notes were taken. Proper consent procedures were followed, per IRB guidelines.

Details regarding informant types and locations are included below with more details in each case study:

TABLE 2: PRIMARY DATA COLLECTION – INFORMANT TYPES, NUMBERS, LOCATIONS

	Tamil Nadu, India	**Nepal**	**Bangladesh**
Location of feedback	Coimbatore (Pollachi), Sathyamangalam, Dharmapuri, Krishnagiri	Kathmandu Valley (interviews and site visits) Surveys: Surkhet, Banke, Kaski, and Lalitpur	Jessore, Bogra
Government/education/non-profits	4	2	4
Agrochemical suppliers	11	3	3
Nursery owners/operators	5	-	5
***Trichoderma* manufacturers/importers**	1 (3 additional manufacturers visited during pilot trip)	2 *Trichoderma* manufacturers, one *Trichoderma* importer	2
Cocopith manufacturers/importers	2 cocopith manufacturers, 1 separation facility	One cocopith importer	One cocopith manufacturer
Farmers	-	3 interviews 401 farmers surveyed	10 interviews, 1 large-group discussion with 20+ farmers

Data analysis methods

Following data collection in Bangladesh, Tamil Nadu, and Nepal, the interviews were transcribed and then the transcriptions and field notes were coded using different iterative coding techniques—topical coding, holistic coding, concept coding, axial coding—all with the intent of reaching conceptual saturation. The lead researcher (R1) who conducted the interviews and oral surveys, took field notes at the end of each day as well as voice memos during field work. A different researcher (R2) transcribed interviews and, using Nvivo, coded both the transcriptions and the field notes using codes based on the research questions and literature. As the initial round of coding progressed, R2 added several additional codes to the codebook that were not originally included but were also related to the research question. R2 then checked her work by reading through the coded material a second time, coding and recoding text as necessary. Following that initial round of coding, researchers grouped those codes according to elements of the diamond model. R1 and R3 then engaged in one additional round of coding each. Points of agreement and difference in the codes were noted in the coding software. There was a high level of agreement between R1, R2, and R3 for the majority of codes. The biggest changes were in adding additional codes to the existing coded data so that many pieces of the interviews and field notes had multiple codes. Table 2 lists all of the qualitative codes according to the elements of the diamond model and agricultural technology. Not all codes were present in all case studies.

TABLE 3: QUALITATIVE CODES GROUPED BY DIAMOND MODEL

Diamond Model Element	Cocopith Codes	*Trichoderma* Codes
Factor conditions	Gender Cost Cultural Norms Education of farmers Natural environment External support	Gender Easy to produce Cost Cultural norms of farmers Education of farmers Time Importer/retailer knowledge Regional differences
Demand conditions	Diffusion of information Health Increased quality Increased yields Increased water retention Reduction in diseases Increasing demand Interest in exporting Interest in the product Poor seed quality Application and use	Health Increased profits Increases quality Increases yield Savings Reduced diseases Uncertainty Diffusion of information Market for selling Easy to use Availability Not-effective Application of the technology Time
Related and supporting industries	Value added products Supply Chain	Product Type Supply chain
Firm Strategy, Structure, and Rivalry	Jobs created Profits Niche product/no competition Job turnover Manufacturing and transportation Quality control Supply Chain	Competitive advantage Jobs created Profits Competition with synthetic chemical companies and others High employee turnover Manufacturing and transportation Quality control Scaling up Marketing of bio-pesticides Supply chain Cultural Norms of manufacturers
Government	Policy and institutional environment External support	Policy and institutional environment
*Note: Not all codes were present for all countries		

A Summary of Supply Chain Impacts

The economic benefits of *Trichoderma* accrue to the people who manufacture *Trichoderma*, those in the supply chain, and the farmers. Differences in institutional, cultural, and transportation factors, mean that the benefits and costs are not realized uniformly across each of the three countries. See Appendix 2 for detailed supply chain maps based on those drawn during informant interviews.

Given that India has the most developed *Trichoderma* supply chain and the highest levels of adoption, researchers started by evaluating the economic benefits in Tamil Nadu. In Tamil Nadu the benefits of *Trichoderma* start with the manufacturers. This includes university labs, extension labs, non-profits such as women's groups, and commercial manufacturers. These groups manufacture and sell *Trichoderma* at a profit, which lead to increases in investment, such as hiring more employees. Additional benefits flow to those who resell *Trichoderma* including small pesticide shops, rural entrepreneurs, or other collectives. There are two separate groups adopting *Trichoderma* in Tamil Nadu; the first is nursery owners. Nurseries use *Trichoderma* in their seedling mix, either by mixing *Trichoderma* directly with composted cocopith, or by buying a seedling growing mix that already incorporates *Trichoderma*. The demand for these healthy seedlings has created a large nursery industry – leading to more stable employment among women. The second group of adopters are farmers that either indirectly adopt by purchasing seedlings from nurseries, or adopt *Trichoderma* through direct application. By using *Trichoderma*, farmers are able to use less synthetic pesticides, which has benefits for their and the health of their family in terms of reducing exposure to pesticides. In terms of cost, the adoption of *Trichoderma* reduces input costs while increasing yields. It is important to note that it does take more time to use IPM practices over synthetic controls, leading to higher labor costs; however, these costs are offset by the benefits of application. Once the *Trichoderma*-produced vegetables leave the farm, consumers continue to accrue benefits. Less pesticide use also means less pesticide residue for the consumer, resulting in possible health benefits later. One additional benefit seen in some areas is that there are now markets for vegetables and fruits produced with lower pesticides. Similar to the way that organics fetch a premium price in parts of the Western world, vegetables produced with less synthetic chemicals can also be sold at a higher price. This premium, if transferred to the farmer, can offset some of the higher labor costs associated with the techniques and also encourage more farmers to grow with less synthetic chemicals.

One potential negative side effect of adopting *Trichoderma* is the uncertainty of effectiveness. There are some diseases where *Trichoderma* has little effect. If a farmer chooses not to use a synthetic chemical spray to prevent a disease unaffected by *Trichoderma*, they risk losing their entire crop.

The economic benefits of cocopith similarly accrue to all members of the supply chain: coconut farmers who receive a higher price; the coconut foods/beauty products industry that is able to sell the husk byproducts, rather than throw them away; coconut fiber manufacturers; cocopith processers; nursery owners and operators; all of the employees of the aforementioned industries as well as ancillary industries such as transportation. Additionally, benefits accrue to farmers who are able to grow healthier seedlings with lower water requirements, and consumers who benefit from a crop grown less expensively and with fewer synthetic chemicals. The adoption of cocopith also has environmental benefits, since those in the industry effectively use this former waste product to enrich the soil. Furthermore, because of its water-holding capacity, cocopith can also be used to increase drought tolerance, reducing overwatering.

The following three case studies explore those supply chain relationships and benefits in greater depth using the Diamond Model Framework. Each case begins with a brief description of the agricultural environment of the country, a review of primary data collection methods, followed by a description of relevant factor conditions, demand conditions, firm strategy, structure and rivalry, and related and supportive industries for the *Trichoderma* industry, and then for the cocopith industry. This information is informed by background information, but mostly relies on primary data collected in the field. Discussions of adoption factors are included within the demand conditions sections.

Case 1: India

India has diverse agro-climates with distinct seasons, making it possible to grow a wide array of vegetables. India is the second largest producer of fruits and vegetables in the world. Tamil Nadu, located in Southern India, is the seventh largest producer of vegetables in India, growing 5.6% of India's vegetables. The state also enjoys the highest vegetable productivity rate in India (Vanitha et al., 2013). Tamil Nadu is the second largest state economy in India, with $230 billion USD in gross domestic product.[51] Agriculture is the principal source of livelihood for more than 40% of the population of this state, though that number is slowly declining. More than half of all women in the state (54.9%) are engaged in agricultural activities, whereas one in three males are engaged in this sector.[52] Agriculture in Tamil Nadu is reliant on modern agricultural technologies including irrigation systems and synthetic fertilizers and pesticides. In the state, 11,780 retail outlets distribute fertilizer of which private retail outlets accounted for 63% and the rest being co-operative outlets.[53]

[51] Vanitha, S.M., Chaurasia, S.N.S., Singh, P.M., & Naik, P. S. (2013). Vegetable Statistics. Technical Bulletin No. 51, IIVR, Varanasi, pp. 250.
[52] Department of Evaluation and Applied Research (2014). Tamil Nadu-An economic appraisal 2011-12 to 2013-14: Agriculture. Retrieved from: http://www.tn.gov.in/dear/Agriculture.pdf.
[53] Ibid

Researchers travelled to four districts in Tamil Nadu (Coimbatore, Sathyamangalam, Dharmapuri, and Krishnagiri) to interview nursery owners/operators (5), cocopith manufacturers (3), commercial *Trichoderma* manufacturers (1), public/non-profit *Trichoderma* manufacturers (3), agrochemical suppliers (11), and agricultural researchers/extension agents (approximately 20 individuals among three group interviews). Interviews with nursery owners/operators and pesticide dealers followed a standard survey-like format at their place of business (See Appendix 1). Interviews with manufacturers included a tour of facilities. Interviews with state-level and national government organizations, such as agricultural research or extension organizations, included both a single interview with the research station director, a group interview with selected staff, and a tour of *Trichoderma* lab facilities if applicable. Most interviews and tours lasted 1-2 hours. Interviews with pesticide shops ranged from several minutes to an hour depending on whether or not the retailers sold biopesticides and could therefore share *Trichoderma* sales figures with researchers. As described in the methods section above, this qualitative data was coded according to elements of the diamond framework. It was then combined with secondary data related to the state of agriculture in Tamil Nadu, as well as additional information about the institutional environment.

Trichoderma

Government/Institutional environment and IPM role

In response to some of the deleterious effects of the Green Revolution in the 1960s, several branches of India's national government adopted policy to "minimize the use of hazardous synthetic pesticides up to as extent as possible & to prevent, manage the insect pests/diseases attack as well as to increase the crop productivity."[54] The Ministry of Agriculture's Department of Agriculture & Cooperation (DAC) launched IPM programming in 1991-92. The Indian Government created 31 Central IPM Centers in 28 states, whose mandate is pest/disease monitoring, production and release of bio-control agents/bio-pesticides, conservation of bio-control agents and Human Resource Development in IPM by imparting training to Agriculture/Horticulture Extension Officers and farmers at the grassroots level by organizing Farmers Field Schools (FFSs) in farmers' fields.[55]

These IPM centers focus on monitoring pests and diseases, conserving and enhancing natural enemies of pests and diseases, production and proliferation of bio-control agents, and human resource development through FFSs. In most cases, farmers do not benefit from direct subsidies or incentives to encourage IPM practice adoption; rather, the government provides extensive marketing and training, including free or reduced cost *Trichoderma*, as well as subsidies to manufacturers of bio-control products (thereby

[54] Department of Agriculture Cooperation & Farmers Welfare (2016). "Integrated Pest Management." Plant Protection. Retrieved from http://agricoop.gov.in/programmesandschemes/plant-protection.
[55] Ibid

reducing costs to farmers). Rao et al (2008) suggested that direct dollar incentives to farmers, such as credit, are not strong factors to adoption for IPM products because these products are relatively cheap in any case.[56] Factors that are more prominent include knowledge of the products and physical access (i.e. supply).

Factor conditions

Factor conditions that contribute to the competitiveness of the *Trichoderma* industry in Tamil Nadu include government support, the presence of Tamil Nadu Agricultural University (TNAU), women scientists and lab technicians skilled in *Trichoderma* manufacturing, ease and low cost of production, cultural norms of farmers, higher levels of education of some farmers, and importer/retailer knowledge and awareness of *Trichoderma*. Factor conditions that hinder the growth of the *Trichoderma* industry include preference for conventional pesticides over biopesticides, lower education among some types of farmers, and knowledge of how to apply *Trichoderma* effectively.

Trichoderma is relatively easy to produce, and TNAU has a standard process of growing *Trichoderma* and packaging it for sale. This process was developed and transferred under the direction of Dr. Sevugapperumal Nakkeeran, who currently works as a consultant with the IPM IL team to develop *Trichoderma* manufacturing capacity across the world. The staff at TNAU have introduced this manufacturing process across Tamil Nadu, including extension and research centers, as well as numerous women's self-help groups. They also assist larger-scale commercial manufacturers of *Trichoderma* in their manufacturing processes and quality testing. Many manufacturing facilities reported receiving equipment subsidies to defray startup costs, leaving the majority of costs of production in labor and raw inputs which are relatively inexpensive. One small-scale *Trichoderma* manufacturer keeps costs low by sterilizing large quantities of whisky bottles obtained from a local recycling plant, and growing *Trichoderma* spores that way. The same manufacturer also uses easily-found inputs, such as carrots and potatoes, as a *Trichoderma* starter.

In every visit to a *Trichoderma* manufacturing facility, except for the government centers, the majority of researchers and lab technicians were women. Researchers observed one class at TNAU where students learned about *Trichoderma* and it was almost exclusively attended by women. The level of education of women in Tamil Nadu and their interest in working in scientific fields positively contributes to the growth and success of the *Trichoderma* industry. For non-commercial producers, such as women's self-help groups, there is an interest in *Trichoderma* manufacturing because these women are able to earn higher

[56] Rao, C.A.R., Rao, M.S., Naraiah, P., Malathi, B., & Reddy, Y.V.R. (2008). "An Economic Analysis of Adoption of Intergrated Pest Management in Groundnut." India Journal of Agricultural Economics 36(1), pg. 99.

incomes than they would in regular agriculture/field work. The women who belong to self-help groups in this study also report that the reason they are engaged in *Trichoderma* production and application is in-part because *Trichoderma* is good for the physical health of their family, as well as environmental health.

Trichoderma is a very well-known and common biopesticide in Tamil Nadu. Though not all retailers surveyed sold *Trichoderma*, every retailer had an awareness of *Trichoderma* and some knowledge of how to apply it. One interesting challenge noted by several pesticide dealers is that in certain areas of Tamil Nadu, *Trichoderma* is known by the most popular strain: *T. viride*, and is called "viride," not "*Trichoderma*." While the *T. viride* strain is effective for some diseases and some crops, there are additional strains that are more effective for other diseases and crops, such as *T. harzianum* (the most popular alternative), as well as *T. asperellum* and *T. hamatum*. Should scientists and extension agents decide that *T. harzianum* is more effective against a pathogen, retailers and extension agents may have a challenge to encourage people to move away from *T. viride* towards *T. harzianum* because of lack of awareness that they are both *Trichoderma* and work in similar ways. Another challenge in terms of retailer knowledge is the competition between conventional and biopesticides. For *Trichoderma* to work effectively, it must often be applied before disease is present. Farmers often go to retailers after disease has been detected, at which point *Trichoderma* application is not always warranted. Another challenge is that retailers often had incomplete knowledge of the shelf-life, proper storing procedures, and method of *Trichoderma* application. If farmers receive *Trichoderma* that has been degraded due to storage mistakes, or has expired, they will not receive the positive benefits of *Trichoderma* application and will be less likely to purchase *Trichoderma* or use other biopesticides in the future.

Demand conditions

Since India has banned a number of synthetic pesticides, especially recently, farmers have been searching for safer alternatives. Five interviewees in India cited the health benefits of using *Trichoderma*, and a TNAU researcher told us that the farmers he works with often choose *Trichoderma* for the health of their family. Several extension officials mentioned that biopesticides such as *Trichoderma* are becoming essential in agriculture because synthetic fungicides are no longer enough on their own to combat evolving diseases. They further shared that demand is increasing because farmers are starting to realize that conventional synthetic controls are not as effective as they once were.

The market for organic produce is also increasing in India, and the government is working to promote organics as well. Organic regulation remains loosely enforced; however, as systems grow and enforcement becomes more commonplace, there could be an increase in the demand for *Trichoderma* as it can be included in an organic agricultural system. TNAU shared the story of a farmer that makes about four times more money when he uses the IPM package on his cucumbers, which includes the application of *Trichoderma*. This farmer was an early adopter and because he had a positive experience with IPM, he also shares the technology with neighboring farmers. Another more technically savvy farmer who manages a permaculture-inspired farm mentioned that when he started using *Trichoderma* in his drip irrigation, it saved his eggplant from wilt. Since he started using *Trichoderma* he has seen an increase in yields and he has shared the technology with neighboring farmers.

The main channels through which information about *Trichoderma* is diffused to farmers is: government/extension, pesticide shops, and farmers themselves. The Krishni Vigyan Kendra (KVK) is a grassroots-type organization funded by the government that serves as a point of connection between the farmer and research. Each district in Tamil Nadu (except for one) has a KVK office. In total, there are 670 KVKs in India. The KVK employs multidisciplinary teams that coordinate with institutions to bring technology to the districts and test their suitability. They hold training for state officials, private extension providers, and pesticide dealers. One of three KVKs visited on the trip shared that 20 years ago the KVK established two labs and trained local women to produce *Trichoderma*. The demand for *Trichoderma* is positively influenced by these KVKs both through selling *Trichoderma* at a reduced cost, and also through education of farmers on how to properly apply *Trichoderma*. Education includes training, demonstrations, and farmer field days. This particular KVK sends regular mobile messages to 4,000 farmers and manages a WhatsApp group of 120 farmers that share information with one another. The KVKs plan on implementing an entrepreneurship initiative where underemployed youths learn how to manufacture *Trichoderma* and then sell it in their local area.

Pesticide dealers are a key source of information for farmers about agricultural inputs and serve an important role in the adoption and proper use of *Trichoderma*. One agrochemical wholesale manager said that in addition to educating farmers, he also trains nursery owners and conducts demonstrations to show them that *Trichoderma* increases germination rates. He claims to be the only commercial seller of *Trichoderma* in the region, and has field staff that promotes it. The research station nearby also sells *Trichoderma*.

Government extension officials say that they promote *Trichoderma* specifically because it is affordable for farmers, easy to produce, reduces diseases, and is environmentally friendly. Though *Trichoderma* is available to farmers under a number of government schemes and through women's groups, *Trichoderma* is not always available commercially. During a survey of all 10 pesticide shops in a centrally located town, researchers found that only two shops sold *Trichoderma*. While the shop owners who sold *Trichoderma* reported a growth in sales, the eight that did not sell *Trichoderma* claimed that demand is low, and because of the short shelf-life of *Trichoderma*, and small margins, it's not a profitable product for them.

A few interviewees mentioned that even though the government promotes the powder form of *Trichoderma*, and it is the only *Trichoderma* product that is currently registered, farmers prefer the liquid formulation. This is because it is easier to use in systems where drip irrigation is present. Additionally, a manufacturer claimed that the liquid is more concentrated than the powder, which makes it easier to transport. Powder is still used by larger farms without irrigation systems because it is easier to mix into farm yard manure (FYM) during soil preparation where water is not readily available.

There is a mentality that synthetic chemicals work quickly and efficiently and it is sometimes hard to break that perception. One fertilizer salesman mentioned that farmers do not think ahead to take preventative measures, which is why adoption of *Trichoderma* is difficult. Another supplier claimed that the adoption of bio-pesticides is difficult because farmers do not want to change what they are accustomed to because of the uncertainty with the adoption of biopesticides. One pesticide salesman who has been selling *Trichoderma* for one year, and formerly worked for a biopesticide company, shared that he has three types of customers. The first type come in asking for *Trichoderma* specifically, the second type come in asking for advice, and the third type come in looking for chemicals. He has 200 total customers, and approximately 30 of them buy *Trichoderma*. He says demand increases when other farmers see that the seedlings of the people using *Trichoderma* are nice and healthy, and then they come to his shop and request *Trichoderma* as well.

Among interviewee types (private and public), there seemed to be some disconnect between the views of government officials, including university officials, and commercial producers and distributers of *Trichoderma* in regards to the popularity and adoption of *Trichoderma*. One extension official exclaimed, "Everyone knows about *Trichoderma*! Tea, coffee, *Trichoderma*!" That same official, however, estimated that of the 24,000 farmers served by that KVK, approximately 1,000 use *Trichoderma*, indicating an adoption rate of about 4.2%. Another large-scale pesticide shop that serves a large region contends that about 90% of farmers are not educated when it comes to biopesticides and sales of *Trichoderma* are low. Another shop owner explained that awareness and knowledge is high near the KVK's, but that knowledge dissipates with the distance away from the KVKs. When we asked a small pesticide shop who purchases *Trichoderma* from TNAU and a local research institute and then resells it, he estimated the adoption rate to be about 40%. The claim that everyone knows about *Trichoderma* and the discrepancies in reported adoption rates indicate that while awareness of *Trichoderma* may be high, actual (active) use of *Trichoderma* remains relatively low.

Firm strategy, structure, and rivalry

Sales of *Trichoderma* happen through many different venues, but manufacturing is done by research and extension centers, private industry, and cooperative groups that are supported by the universities or extension networks. There are approximately 150 commercial *Trichoderma* producers in India. The increase in demand for *Trichoderma* has led to a proliferation of commercial producers, in some cases leading to refinements in manufacturing techniques, hence lowering costs, as well as an increase in quality standards. Manufacturers interviewed claimed that sales are steadily increasing at between 7-15%. Manufacturers sell a variety of biopesticide projects, in addition to selling *Trichoderma* by itself. In some cases, they give the *Trichoderma* product a new name, such as "Biocure-F," and in other cases they include *Trichoderma* in a biopesticide formulation with additional ingredients such as *Pseudomonas*. TNAU and manufacturers claim that Tamil Nadu is the #1 state for *Trichoderma* in India.

In terms of commercial manufacturing, one *Trichoderma* company owner explained that he sells *T. viride* mostly through telemarketing throughout India. He sells *T. harzanium* in the hills area where ph is low. He sells a custom mix of *T. viride* and *T. harzanium* for cardamom growers in Kerala. He direct markets *T. viride* in 4 states, and direct markets *T. Harzanium* in 3 states. He consults with a sugarcane cooperative that has replaced copper fungicides with *Trichoderma*, leading to positive effects on soil health and runoff.

Commercial manufacturers face competition from research institutions who also sell *Trichoderma*. The commercial manufacturer shared that the government sells *Trichoderma* at 200 rupees per kg, while a commercial price is 280 per kg. The KVKs themselves reported selling *Trichoderma* at 100 rupees per kg. One KVK shared that they sell *Trichoderma* on a seasonal basis. They produce 2-3 tons per year of the powder, and 1,000 liters of liquid. That KVK has about 60-70 laborers, of which only 4-5 are skilled laborers. The others are involved mainly in blending and packing. Of the 30 KVKs in Tamil Nadu, that KVK estimates that only 6-7 produce *Trichoderma* on that scale.

The manufacturing facility visited offers room and board to workers as part of their compensation package. Salaries for technical staff is between 8,000 – 15,000 rupees per month. There are other "casual laborers" employed who receive 220 rupees per day plus room and board. In terms of economic impact, we found that many of the women employed either in *Trichoderma* production or in the nursery industry described in the following section worked previously doing seasonal manual labor in the fields. They said that while the daily wage is the same, the nursery and *Trichoderma* industries afford them stable year-round employment that is less physically demanding.

One major challenge facing *Trichoderma* producers is competition with synthetic chemical pesticide companies. While India has banned certain synthetic pesticides, one *Trichoderma* producer mentioned that he cannot compete with corporations that sell conventional pesticides because the market promoters who sell those pesticides participate in large incentive programs. Furthermore, when used properly, synthetic pesticides have immediate results and high rates of efficacy. The immediate risk the farmer takes when choosing a synthetic pesticide over a biopesticide, such as *Trichoderma,* is much lower. Often, farmers operating at low margins have low discount rates, meaning that they outweigh their present circumstance over their future circumstance. This might lead them to choose the synthetic pesticide over the biopesticide even if in the long term, the biopesticide might lead to higher yields and a host of positive physical and environmental health benefits.

Competition between *Trichoderma* companies is also a challenge for small and large-scale manufacturers. One small-scale manufacturer explained that one of the largest adopters of *Trichoderma* in his region of Tamil Nadu is the sugar cane industry. That industry relies heavily on contract farming that requires farmers to use specific inputs and practices in their fields. Those companies have preferred *Trichoderma* suppliers that are able to produce large quantities of *Trichoderma* at lower prices. He suggested that the large-scale manufacturers might produce a lower quality product at a lower cost, leaving this manufacturer out of the market. Visits to two large-scale manufacturers with senior *Trichoderma* scientists on the initial field visit revealed that those manufacturers adhere to strict quality standards and efficacy testing. However, it is possible that in a marketplace where differentiation between types of *Trichoderma* is near impossible, coupled with limited shelf life, there is potential for lower quality *Trichoderma* products to be sold in the marketplace at a lower cost.

Though state and local governments, as well as academic institutions such as TNAU, have set rigorous quality standards, feedback from manufacturers and farmers indicates that the those standards are not uniformly enforced, leading to issues of quality control. One manufacturer claimed that there are some companies who will buy *Trichoderma* produced at his factory, dilute it, and repackage and relabel it as their own. Furthermore, we found that agrochemical supplies, researchers, and extension agents all gave different answers when we asked about the temperature at which it was appropriate to store *Trichoderma*, as well as the expected shelf life.

In addition to manufacturing *Trichoderma* for domestic consumption, companies also export *Trichoderma*, increasing the external flows of money into the national and regional economy. One barrier to exportation is that only the powder form is able to be exported at this time, while the liquid form is often in higher demand and has a lower transportation cost, but cannot be exported. One *Trichoderma* producer explained that the reason for this is that there is not enough data from the universities about the effectiveness of the liquid formulation which would be required for registration for export. Furthermore, another *Trichoderma* producer claimed that there is a quarantine for bioproducts that are exported legally. Depending on weather conditions, the time spent in quarantine in a hot environment could degrade the quality of *Trichoderma*. Reductions in perceived effectiveness would limit international demand for Indian products.

Related and supporting industries

As indicated earlier, the main industry that supports the *Trichoderma* industry is agriculture, as they are the primary purchasers and users of *Trichoderma*. This includes farms of various sizes, from smallholders to large contract-farming (sometimes called "estates"), nursery operations, pesticide wholesalers and dealers, and all of the tertiary industries that allow *Trichoderma* to be transported between those. In Tamil Nadu, the highway infrastructure is advanced, allowing for easy transport of *Trichoderma* throughout the region. Beyond farmers that were discussed in the "demand conditions" section above, the nursery industry is a key related and supporting industry for *Trichoderma* that has experienced rapid growth in Tamil Nadu, in large part because of the use of cocopith as a growing medium. While the nursery industry is explored in more depth in the following cocopith section, a brief description of the use of *Trichoderma* is included here as well.

The nursery industry commonly uses *Trichoderma* when growing seedlings. There are several ways nurseries incorporate *Trichoderma* into their seedling mix. Some nurseries make their own growing medium which includes *Trichoderma* either to facilitate composting, or as a nutritive addition. Other nurseries buy a growing medium that already has *Trichoderma* in it. Interestingly, the researchers we spoke to at TNAU and the KVKs were relatively unaware that some nurseries purchase a growing medium that already has *Trichoderma* mixed within it, indicating that it may not be common practice in all regions. Still other nurseries practice "root dipping," where they carefully lift seedlings out of the plastic tray and then dip them in a *Trichoderma* solution before sale. All nurseries visited except for one used *Trichoderma* in their seedling mix, either by adding it directly, or purchasing a growing medium that has *Trichoderma* listed as one of the ingredients. One nursery owner shared that he used to use *Trichoderma* but did not see a direct benefit that justified the cost, given that the nursery industry is a relatively risky business because of weather variability and seed quality concerns. The finding that many nursery owners use *Trichoderma* in their seedling mix suggests that the adoption of *Trichoderma* could be extremely high in those areas where farmers purchase seedlings. Given both the difficulty of educating and encouraging the adoption of *Trichoderma* for individual farmers, targeting extension efforts towards the nursery industry, and encouraging as many as possible to include *Trichoderma* in their seedling mix could lead to almost 100% adoption of *Trichoderma* by farmers, allowing many more farmers to benefit from *Trichoderma*, whether they are aware of how to properly apply it or not.

Cocopith

Factor conditions

Over the last 20 years, the cocopith industry in India has grown and has become essential for the country's seedling nurseries. Cocopith was once a waste product that was dumped and not managed properly, but now it has become an industry of its own and has increasing export value. The Coconut Development Board (CDB) is a statutory body established under the Ministry of Agriculture, Government of India for the integrated development of coconut cultivation and industry in the country with focus on productivity increase and product diversification. Cocopith is one of thirteen coconut products advertised on the CDB website. According to CDB, India is the premier coir manufacturing country in the world. There are several incentive schemes to encourage the manufacture and use of cocopith. The "assistance for organic manure units" seek to promote the use of organic manure like vermicompost, coir pith compost, ordinary compost and FYM in coconut holdings. Financial assistance of Rs.20000 per unit or 50% of cost of production is provided for setting up of a unit.[57]

The country has also been influential in providing institutional support to the industry through its Coir Board. This entity promotes the sale of cocopith and is responsible for setting the price of the husk and the coconut—they have an electronic application for this which makes this information more accessible for farmers and cocopith producers. Additionally, the government has subsidies to support the coir industry and has been promoting coir clusters.

One KVK director shared that cocopith is a recent technology for farmers that has only been around for about 10 years. The proliferation of cocopith came directly from the coconut industry, as managing cocopith waste was becoming a major nuisance for them. The KVKs are beginning to work with the new nursery industry, extending training to them. There are plans for the government researchers to conduct an economic impact study on the nursery industry which will provide more information about the benefits of cocopith.

In terms of processing and selling cocopith, major challenges arise during the manufacturing process because of weather concerns. For example, one factory owner in particular explained that he cannot work year-round because of the monsoon season. When it rains, his factory has to stop production for 10 days

[57] Coconut Development Board. (n.d.) Schemes for Coconut Development Board. Retrieved from: http://coconutboard.nic.in/Scheme.aspx#Index

which makes it difficult to maintain full-time employees year-round. Another factory owner mentioned that the region has had a drought for the last three years which has negatively impacted the coconut supply, and hence raised the price of cocopith.

Demand conditions

The international demand for cocopith in India is reported to be higher than the domestic demand. One factory owner mentioned that he started his factory because he saw the international demand for the product. Most factory owners said that the overwhelming majority, approximately 90 - 99% of the cocopith that is processed is made into compressed blocks and shipped internationally. International markets cited included Europe and Asia. One cocopith manufacturer who has his own website and was able to explain his manufacturing and marketing process in the greatest detail, finds buyers for cocopith via Alibaba.com mainly in the upscale European markets. Some cocopith manufacturers did not know where the cocopith was being distributed to, because they did not sell directly to international clients, and were instead selling to “middlemen” who aggregate and sell to the highest bidder. One cited reason for the increase in demand for cocopith is because European countries like Norway are no longer selling peat moss because of environmental concerns. Cocopith is seen as an appropriate (though lesser) substitute.

The increase in international demand has a slight negative effect on domestic consumption of cocopith because the cost of raw cocopith has become more expensive for nursery owners. One nursery owner explained that when he first started his nursery 4 years ago, a truckload of raw cocopith cost 4,000 rupees. Now a truckload costs 20,000 rupees, or five times as much. Domestic demand is primarily concentrated with nurseries and tertiary industries, such as seedling mix companies. The nurseries visited on the initial scoping trip were all concentrated in the Coimbatore district. Within that district, the town of Pollachi is known as a central hub of coconut farms and cocopith production. The nurseries in Coimbatore all manufactured their own seedling mix, washing, drying, and composting raw cocopith on their own. Those nurseries claimed that their process was a standard one. However, on the subsequent trip, researchers travelled to additional districts in Tamil Nadu and discovered that many nurseries in those districts, perhaps because they are further away from Pollachi, either buy a coconut-pith-based growing medium, or purchase already composted cocopith. There are both commercial manufacturers of cocopith-based growing medium, and also several mentions of women’s self-help groups also making and selling coconut-pith based growing medium. One KVK reported recently training 20 women to turn coir waste into a growing medium.

All nursery owners interviewed were extremely knowledgeable about the benefits of using cocopith. One nursery owner focused on the way that cocopith helps promote root establishment and growth, while another nursery owner focused on the moisture retention benefits. Though the initial expense for farmers to purchase seedlings at a nursery is higher than direct seeding, farmers are reportedly satisfied and willing to pay the higher initial cost because of lower rates of seedling death and greater plant vigor. Purchasing seedlings rather than direct seeding also saves on labor costs.

The bricks produced for commercial export are less popular among domestic consumers. One nursery owner claimed that he preferred to buy cocopith that has already been steamed and packaged in bags because the bricks are too dry, and limited water availability makes it difficult for him reconstitute the bricks. This presents a unique challenge for manufacturers in deciding what type of cocopith product to produce, because on one hand, reducing the moisture content and making the cocopith into bricks is more economical for export where the majority of demand is, but on the other hand, it becomes too dry to be sold to local markets. Many of the cocopith manufacturers seemed unaware of the use of cocopith in the nursery industry, or considered it such a small part of their business that they were uninterested in catering to that market.

One challenge for nursery owners is that the quality of cocopith tends to vary, even though it is sold on a commodity market with a constant price. The variation in cocopith leads to inconsistent germination rates. The nursery industry in India is considered risky by many owners because of variable weather conditions and seed quality; this makes a consistent growing medium important.

Firm strategy, structure, and rivalry

Cocopith factories that solely process the by-product from coconut fiber factories have created jobs in the Tamil Nadu region with approximately 100 cocopith factories in the region. Labor is reportedly a challenge in the industry, as the work is difficult, so there is job turnover. For this reason, the factories rely on migrant labor from Northern India. Of the cocopith factories researchers toured, women were mostly engaged in the work of collecting the fiber to separate it from the pith before putting it into machinery that further separated and sometimes bundled it, while the men primarily were engaged in making the bricks and manually bundling and loading the fiber to send to fiber processing factories. At each of the factories, at least half of the workers are female. When asked about the wages of men vs. women, the manufacturers said that the men make more than what women make because the men "work harder." The salary for laborers is roughly 250 rupees per day for women, and 300 rupees per day for men. In addition to this daily wage, most workers are also provided room and board. The number of people employed at each factory we toured ranged from 10-35.

Because of monsoon season, work in the cocopith factories is seasonal. One manufacturer reported that when there's a rainy day, you have to stop production, and it takes up to 10 days for the pith and fiber to dry out so it can be processed. For that reason production only happens around 100 days a year, so employment is often on a contract basis. Another factory owner reported sharing laborers between that factory and another adjacent one.

Related and supporting industries

The supply chain that supports the cocopith industry is extensive. It starts with the coconut growers who sell coconuts to manufacturers of beauty and food products, such as coconut oil, coconut milk/cream, coconut chips, etc. The waste product from the coconut beauty and food products industry is the coconut husk. The husk is then sold to separation facilities, who separate the pith from the fiber. The fiber can be made into a variety of products such as mats, mattresses, and ornamental planters. It can also be used with minimal processing as livestock bedding, and mulch. Because of the huge volume of cocopith produced at a typical separation facility, most pith is made into blocks at the separation facility, while the fiber is taken elsewhere for processing. All along the cocopith supply chain, there are “middlemen” who are somewhat akin to commodity traders, buying and selling and trading coconut products throughout the supply chain. Some cocopith manufacturers report using these middlemen, while others prefer to make direct sales to buyers to receive higher prices.

For example, one cocopith manufacturer shared that a trader purchases cocopith directly from the factory, and then sells it to an exporter. The trader brings exporters to the region to view the quality of the product at each factory. Once the exporter agrees to purchase it, the trader then negotiates the price and volume. The manufacturer would prefer to sell directly to the buyer to get higher prices but is unable to. The trader will buy the cocopith bricks at 14 rupees per kg, and then sells it to the exporter for 20 or 25 per KG. To ensure the quality, the trader uses a moisture reading device.

Another related industry is the manufacture of the separating machines. In Bangladesh, for example, the sole cocopith company there purchased their machinery for both separation and block making from an Indian manufacturer.

The governmental support for *Trichoderma* and cocopith is very strong in Tamil Nadu. It is perhaps the most influential of the factor conditions. The combination of strong research into *Trichoderma* manufacturing, transferring the manufacturing process to private and non-profit manufacturers, and government subsidies for equipment all positively support the industry. Further research into the increasingly popular liquid formulation would lead to an increase in domestic and international *Trichoderma* sales. Similarly, the government funded Coir Board plays a large role in the expansion of cocopith facilities largely through incentives. In terms of demand conditions, the burgeoning nursery industry plays a role in increasing the domestic demand of both *Trichoderma* and cocopith. Other influential demand factors include higher levels of education among farmers and the prevalence of drip irrigation systems that make *Trichoderma* application easier. International demand for cocopith is growing, increasing both the domestic and international price paid, which could limit the quantity demanded domestically. Competition between synthetic and biopesticide manufacturers, and between biopesticide manufacturers themselves, while potentially helpful in spurring innovation and driving down costs, is also a challenge in a marketplace where quality control standards are not uniformly enforced. A lack of uniform storage and application standards (or at least a general lack of knowledge of such standards) also further limits a farmer's ability to see whether or not the efficacy of the *Trichoderma* purchased was due to manufacturing procedures, or some sort of storage and transportation challenges. A focus on getting the nursery industry to effectively use *Trichoderma* both through stronger supply chains between cocopith and *Trichoderma* manufacturers seems to be an area with potential for strong returns should the IPM IL wish to increase the adoption of *Trichoderma.*

Case 2: Bangladesh

Bangladesh is a densely populated country of more than 162 million people (World Population review 2016) with more than 70% residing in rural areas (FAO, 2014).[58] Bangladesh has a primarily agrarian economy with 16% of the country's GDP dependent on agriculture and 39.07% of the total labor force employed in agriculture, though that number has declined significantly in the last two decades (World Bank, 2017).[59] The country's agricultural productivity (agriculture value added per worker, constant USD) has significantly increased from 408.32 USD in 2000 to 768.91 USD in 2016. The country has 37,573,000 acres under agricultural production of which 48.22% is irrigated (FAO, 2014).[60] Agriculture in Bangladesh is heavily dependent on weather, and entire harvests can be wiped out in a matter of hours when cyclones hit the country. In Bangladesh, rice and jute are the primary crops produced, followed by wheat and vegetables. Major fruits produced in the country include mango, guava, blackberry, custard apple, tamarind, Indian palm, jackfruit, papaya, pineapple, wood apple, lemon, betel nut, banana, coconut, lychee, pomegranate, date palm, and ficus. Fertilizer usage in Bangladesh has grown over the years. FAO reports an average of 217.5 kg used per hectare of agricultural land for the period 2002-2015 with a

[58] Country statistics: Bangladesh. Food and Agriculture Organization of the United Nations. (2014). FAOSTAT statistics database.
[59] World Development Indicators Database-Bangladesh. (2017). World Bank Group.
[60] Country statistics: Bangladesh. Food and Agriculture Organization of the United Nations. (2014). FAOSTAT statistics database.

minimum of 160.3 kg per hectare of arable land in 2003 and a maximum of 297.7 kg per hectare of arable land in 2015.[61]

Research focused on two primary agricultural areas: Bogra and Jessore. Bogra, the industrial city of North Bengal, is also known for its modern irrigation and scientific cultivation system. The city has around 714,000 acres of net cropped area (2011). Major crops grown in Bogra include aus, aman, Boro paddy, jute, wheat, potato, betel leaf, vegetables, spices, pulses, oilseed, cotton, sugarcane, etc. Paddy (rice) covers about 76.05% of the temporary cropped gross area. Jessore, a district in the Khulna Division, is located in southwestern Bangladesh. The district has around 370,263 acres of net cropped area.[62] The district produces a variety of crops year-round, including paddy, jute, sugarcane, tuberose, date, jackfruit, papaya, banana, litchi, and coconut. In the past three decades, improvements in environmental and technological parameters such as soil character, rainfall, relative humidity, groundwater level, as well as availability and use of various agricultural inputs, modernization of cultivation method, and improvement in transport and marketing systems, have enhanced agricultural production.[63]

Researchers travelled first to Dhaka to meet with IPM IL staff and tour the lab facilities of the Bangladesh Agricultural Research Institute (BARI). Then they travelled with two BARI scientists to Jessore and Bogra to interview the sole cocopith producer, The Mennonite Central Committee (MCC) which is the key non-governmental organization working on diffusing IPM technologies through other non-profits, two for-profit and non-profit biopesticide manufacturers, farmers who produce Tricho-compost, farmers who use Tricho-compost, and farmers' cooperatives. While there is a nursery industry in Bangladesh, only growers of ornamental plants use cocopith. Researchers also visited farmers who grow seedlings to sell to others in open cultivation.

Trichoderma

Factor conditions

The most critical factor condition that supports the *Trichoderma* industry in Bangladesh is BARI. That research lab produces *Trichoderma* spores and gives or sells them to farmers, NGOs, the non-profit *Trichoderma* producer, Grameen Krishok Sohayok Sangstha (GKSS), and the sole commercial *Trichoderma* producer, Ispahani. From there, the farmers and GKSS multiply the *Trichoderma* by

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[61] Country statistics: Bangladesh. Food and Agriculture Organization of the United Nations. (2014). FAOSTAT statistics database.
[62] Bangladesh Bureau of Statistics (2013). District Statistics 2011 Jessore. Statistics Division, Ministry of Planning, Dhaka, Bangladesh.
[63] Raufe, A. (2015). Analysis of changing agricultural pattern in Jessore: Environmental and social aspects (Doctoral dissertation, University of Dhaka).

applying it to compost, harvesting the leachate that runs off the compost, and applying that leachate to additional batches of compost to continue the process. Ispahani multiplies *Trichoderma* using the lab-based manufacturing process seen in India.

Farmers, therefore, both manufacture their own Tricho-compost and Tricho-leachate, and if they produce enough, are able to sell Tricho-compost and Tricho-leachate to other farmers. This is enabled by the fact that the composting process is relatively straightforward, and many farmers who were part of an initial Tricho-compost project funded by MCC, were supplied with concrete rings at a reduced cost. One limitation to this method is that it is somewhat labor intensive to mix the compost, and it takes up to 6 months for the compost to be finished. Researchers interviewed farmers who were specially selected several years ago to participate in this Tricho-compost program. They found that the majority of those farmers did not produce the maximum amount of Tricho-compost that they could because 1) some of the concrete rings had degraded, and they did not have access to additional concrete rings, and 2) they could not always find the time to tend to their Tricho-compost, so they either had their wives engaged in Tricho-compost manufacturing, or hired day laborers to help with the mixing.

Demand conditions

Most farmers that the researchers spoke to make their own Tricho-compost with spores directly from BARI or through MCC. To apply *Trichoderma*, they mix the finished Tricho-compost solids with the soil during land preparation, and also use the lecheate as a foliar spray. This method of application is congruent with the practices that farmers already implement, making the adoption of *Trichoderma* easier. Unlike in the other two countries researchers visited, farmers had remarkably similar answers to the question: “how do you apply *Trichoderma*?” While mixing with the soil during land preparation is an IPM recommended practice, the farmers most commonly stated that they sprayed Tricho-leachate at 15 day intervals. This indicates that farmers are used to spraying on a regular schedule, potentially because of their familiarity with a synthetic pesticide application schedule.

One issue with this spraying schedule was illustrated by the manager of a regional biopesticide shop. He estimates that only 10% of the people who spray Tricho-leachate are doing it properly. The private extension agents and salesmen he manages frequently report that farmers are mixing commercially purchased *Trichoderma* with 4-5 commercial synthetic pesticides together in one sprayer, calling it a “cocktail.” Mixing *Trichoderma* together with synthetic pesticides in this way kills the *Trichoderma* spores. With no benefit, the adoption of *Trichoderma* by these farmers is a net loss to them because they are not realizing any of the benefits. When researchers asked the cooperative farmers who made their own Tricho-leachate what they mixed it with, they said that they only mixed it with water, and never added any synthetics. There may, therefore, be a difference in the way that people who make their own Tricho-leachate apply it, and the way that those who purchase *Trichoderma* powder or liquid from commercial retailers and apply it, with the majority of commercial buyers using it improperly.

Farmers who are using *Trichoderma* properly on their fields have experienced benefits as a result. For example, two interviewees and a focus group of farmers mentioned that the quality of their vegetable products increased specifically in terms of taste, how they look, and their size. Furthermore, three farmers and a focus group of farmers explained that they experienced increased yields since using *Trichoderma*. Finally, farmers, producers, and researchers all mentioned that *Trichoderma* has reduced diseases, namely soil-borne fungal diseases. Farmers from this group reported that they avoided applying *Trichoderma* to cauliflower because they found that it caused root rot. An extension scientist explained that this effect is due not to the *Trichoderma*, but that compost needs to be applied at a lower rate because its high moisture content is not optimal for cauliflower. In this case, it might be beneficial to use *Trichoderma* powder, rather than Tricho-compost.

Proper application, cultural norms, and awareness of alternatives to synthetic pesticides all influence demand conditions for *Trichoderma*. The majority of farmers that researchers spoke to had high awareness because they were part of a collective that aggregates and sells pesticide-free vegetables. When asked whether or not their neighbors who were not part of the collective were aware of *Trichoderma* or used it, they claimed that most did not. The majority of those farmers, however, could identify one or two neighbors that now used *Trichoderma* because that farmer asked to be trained in making Tricho-compost after seeing the positive benefits. Education of farmers, through demonstrations and trainings, is one of the largest barriers to *Trichoderma* adoption. Five separate interviewees alluded to the importance of education.

Some of the major challenges manufacturers felt with respect to *Trichoderma* is that interest in biological control products is low. However, this may relate to a lack of interest in commercial *Trichoderma* products because farmers produce their own Tricho-compost and leachate, which could disincentivize them from purchasing at a pesticide shop. One *Trichoderma* producer felt if there was a mass campaign to promote *Trichoderma* then adoption would likely increase.

In terms of shelf life and quality, there are varying opinions regarding the shelf life and optimal temperature for the storage of *Trichoderma*, even among researchers and extension agents. This may contribute to the reason adoption is low because *Trichoderma* application is more labor intensive than conventional practices, so if farmers are not applying it correctly or are purchasing products that are not effective because they haven’t been stored correctly, they will not realize a positive net benefit, and be unlikely to continue using it. In terms of the differences in shelf life of the powder vs. liquid forumations, Ispahani and BARI were both in agreement that the liquid cannot be preserved out of refrigeration for more than seven days. The powder formulation is good for one year. Ispahani, therefore, stopped marketing the liquid formulation and instead recommends that farmers mix the powder with water for spraying. They also sell a product called Biorama Solid, similar to what GKSS sells. It is *Trichoderma* that has been mixed with some solid ingredients, perhaps composted manure, and looks like small pebbles. When asked about the difference between the Biorama Solid and Tricho-compost, the informant shared that they are roughly the same, but that poor farmers can easily manufacture the compost at a low cost in comparison with the solid.

Though farmers report that the quality of their vegetables grown with *Trichoderma* is higher, there is limited demand in Bangladesh for organic or pesticide-free vegetables, meaning that there is no way for farmers to differentiate their vegetables from those grown with synthetic pesticides, and they are thus unable to receive higher profits. There is one center in Bogra that buys a limited amount of organic vegetables from farmers, packages them under an “organic” label, and sells them at an upscale market in Dhaka. The amount of vegetables they can sell is limited because of limited market demand.

Trichoderma is not widely commercially available in Bangladesh. Farmers from a focus group explained that there may be 20 pesticide shops in their village but only one of those sells bio-pesticides which reinforces the notion that the availability of bio-pesticides is still low in Bangladesh. One farmer mentioned that he did not produce enough *Trichoderma* to use on all his plants and did not want to buy it commercially, so he used it on a priority-basis. While synthetic pesticides are ubiquitous in Bangladesh, one farmer explained that synthetics are twice as expensive as using *Trichoderma*. One of the primary reasons farmers seem to adopt *Trichoderma* is that it is cheaper than purchasing synthetic chemicals.

Firm strategy, structure, and rivalry

Trichoderma is a relatively new agricultural technology in Bangladesh. There are two commercial biopesticide producers, one private firm, Ispahani, that manufactures and distributes a range of biopesticides, and one non-profit producer GKSS, that produces a range of *Trichoderma* based products. Their firm structures and supply chains are relatively similar; however, each does not consider the other competition. While there is a lack of private biopesticide producer competition, there is a vibrant NGO sector producing *Trichoderma*-based products and educating farmers about bio-products. The MCC works directly with researchers at BARI to collect *Trichoderma* spores, and then train other NGOs on how to make Tricho-compost. One graduate of this program is the aforementioned non-profit producer GKSS.

A major challenge in Bangladesh, according to interviewees, is that biopesticides have to compete with synthetic pesticides. For example, some retailers do not want to sell biopesticides because they do not make as much money as they would selling synthetic pesticides. *Trichoderma* is reportedly half the cost of synthetic pesticides that treat similar fungal diseases. One reason why *Trichoderma* is produced by NGOs and by individual farmers is because it is hard for biopesticides to enter the synthetic market and compete directly with them. There are an estimated 300-350 pesticide companies in Bangladesh, whereas there are only two commercial biopesticide producers. MCC explained that NGOs are integral to the dissemination of biopesticides in Bangladesh because there is a lot of dishonesty in the commercial market. Hence, their focus on increasing the capacity of NGOs to produce *Trichoderma* and train farmers in *Trichoderma* production.

Researchers spoke to another two farmers who had decided to form a *Trichoderma* collective. Over the course of the year, farmers who were interested in becoming part of the collective contributed enough money for them to purchase a large set of concrete rings. The plan was for them to collectively gather the material needed to make the compost, receive *Trichoderma* spores through MCC, and then either trade off on the labor to make the Tricho-compost, or hire day laborers to make it. They, together with MCC, were extremely excited about this prospect, because compost is the preferred way to apply *Trichoderma*, and many farmers claimed that they had to ration their Tricho-compost because they were unable to produce enough on their own. These farmers seemed wary of purchasing *Trichoderma* in the shops because they believed the quality of their homemade Tricho-compost was higher than what they could purchase.

Limited electricity and harsh road conditions negatively affect the growth of the *Trichoderma* industry. It can be difficult to produce *Trichoderma* on a larger scale because of the requirement for cool temperatures, and the high cost of transportation disincentivizes commercial producers from scaling. While the private commercial *Trichoderma* producer has quality control measures in place, there are no formal systems for checking the quality of *Trichoderma*. When researchers toured the GKSS facility, they saw that several of the labs that were built for testing quality were unused. Furthermore, there were a range of *Trichoderma* products, including one for aquaculture, which had not been verified for effectiveness in a scientific setting. There were other biopesticide mixes that had similarly been untested but were distributed commercially.

The biopesticide manufacturers, both for-profit and non-profit, explained that employee turnover is extremely high in their distribution channel. Warehouse managers and salespeople frequently leave the biopesticide companies to work for synthetic pesticide companies because of their higher wages and higher incentives for selling. Finding reliable distributers and salespersons remains a challenge.

Registering biopesticides in Bangladesh is challenging. One interviewee shared that one problem with getting biopesticides registration is that it requires the product to be shown to be effective over multiple seasons, whereas to register a synthetic pesticide, efficacy needs only to be shown over one season. While GKSS was able to register Tricho-compost, they have been unable to receive a registration for the other bioproducts they sell, and therefore sell them under the Tricho-compost label, since the other products are a byproduct of the Tricho-compost. GKSS first attempted to apply for registration status in 2007 when there was no formal way to register it. They worked together with the Ministry of Agriculture over three years, and spent a great deal of money to get the registration. The process included paying researchers for trials, receiving registration from various local and central offices such as the local chamber of commerce, environmental department, and others. They contend that after going through this process, it is slightly easier to get a formal registration. It costs approximately 1-2 years and 100,000 tahka per product in addition to 60,000 per trial with multiple trials required.

Government

One way to increase the demand for *Trichoderma* would be for farmers to receive higher prices for vegetables produced using limited or no synthetic pesticides. For this to happen, there needs to be a way for consumers to differentiate vegetables produced with limited or no synthetic pesticides. However, testing for pesticide residue at markets is not feasible and there is limited government support for such measures.

One researcher shared that in 1998, there were IPM clubs for farmers organized by the government. If you ask a government official, they will tell you that there are millions of IPM clubs across the country; however, you can’t actually find anyone who belongs to one now.

When asked about government policies or incentives that have been beneficial in growing the sales of *Trichoderma*, one manufacturer said that the government has been trying to promote Tricho-compost at the field level. The government has extension officers that work directly in the field, and advise farmers to use *Trichoderma*.

Cocopith

Factor conditions

Bangladesh produces large quantities of coconuts, thus the availability of coconut husks from which to create cocopith is high. There are numerous factories that separate the fiber from the pith and use the fiber to make a variety of products used both in Bangladesh, and shipped internationally. For the most part, the pith is still seen as a waste product. There is one factory in Bangladesh, located in Jessore, that takes cocopith, dries it, and turns it into bricks. The major challenge they have, however, is that because of the high frequent rainfall, it is difficult to dry cocopith and maintain that low moisture level after it is made into bricks and packaged. An additional challenge is land availability. Bangladesh is a very densely populated country, and dry land that would not be affected during monsoon season comes at a premium. Drying cocopith takes a lot of space, so both obtaining a large enough space, and constructing a structure that would keep the cocopith dry is unfeasible.

Labor is relatively inexpensive in Bangladesh and women often work manual labor jobs, though often in different roles than men. This labor availability is positive for the cocopith industry which requires workers to manually separate the husk from pith, operate machinery, and transport the pith to the ports where it is exported.

Bangladesh is home to the USAID Agricultural Value Chain (AVC) project, which supports the cocopith manufacturer we spoke to. The project sent him to a workshop in Europe to learn about cocopith processing, and where he met his current buyer from South Korea, and also gave him the equipment to make bricks.

Demand conditions

Cocopith is not as commonly used by farmers in Bangladesh as it is in India and Nepal. While farmers do use transplants, depending on the crop, they obtain those transplants from other farmers who raise the seedlings in large outdoor beds made of soil and compost. International demand is therefore higher than domestic demand.

On the domestic demand side, the nurseries visited sold only ornamental crops, and not vegetable seedlings. Two sources explained that small-scale vegetable farmers in Bangladesh do not understand how to use cocopith and commercial ornamental growers are the primary cocopith users. One ornamental nursery owner believed he was the only one using cocopith in his town, apart from commercial farmers, however when researchers visited the larger scale farmers, they did not see any use of cocopith. He purchases “cocodust” for 3 taka per kg and buys about 4 tons per year. Since using cocopith, the nursery owner noted that growth and sales have increased because the quality of his seedlings has improved. Additionally, this nursery owner explained that one of the largest advantages of using cocopith was that it increases the water capacity of the soil. Despite these benefits, adoption is low in part because farmers are not educated about how to use cocopith and plastic trays are not available in Bangladesh.[64] Thus, a lack of technical knowledge in addition to not having access to plastic trays are the major barriers to adoption in

[64] The plastic trays are seen by some as a necessary part of the technology in India, but not Nepal. Researchers could find no scientific studies that compared cocopith in plastic trays vs. seedling beds.

Bangladesh. Researchers did observe someone leaving the BARI research institute with plastic trays, so it is possible that at the present time they are only used for research.

As evidenced through the India case study, international demand for cocopith is extremely high. If the company could increase their production of cocopith bricks via a solution for how to dry the cocopith in spite of rainy weather and limited land space, then the cocopith manufacturers would have higher profits. Furthermore, if local farmers started using cocopith for raising seedlings, then sales could increase as well. The business owners have attempted to grow domestic demand by going to local farmers, flower gardens, and people who sell trees, to teach them how to use the cocopith, but they claim that they were not interested. They did contend in a later part of the interview that part of this lack of interest was that the pith was not yet washed, so it wasn't ready for use, and that they were able to sell some locally.

Firm Strategy, Structure, and Rivalry

The sole cocopith company in Bangladesh started the new factory about 1.5 years prior to the interview. They first heard about cocopith for agriculture from watching Chinese agricultural videos on the Internet. While they now have the equipment needed to produce bricks, and a buyer who will buy as much as they can produce, the challenge of drying to pith is paramount. The Korean company ordered 60 shipping containers of pith, and thus far the company has only been able to deliver three of them because of their inability to dry the pith. They attempted to dry it in a kiln, however, the heat ruined the structure of the pith, rendering it useless for agricultural purposes.

From their fiber factory, the owners of the company produce five tons of pith per day, and are only able to sell 10 tons per year at a price of 12,000 taka per ton to the local market. In 1.5 years, they were able to sell three container loads of 44 tons each to Korea. If they were able to overcome the drying challenge, it would be an incredible benefit to business. Additionally, there is a domestic buyer in Bangladesh, a tea plantation, that is interested in the pith if it can be transported in brick form. The fiber and pith factories employ about 100 workers, with half working with the pith, and half with the fiber. Most of the workers observed in the factories were women, receiving an average salary of 250-300 taka per day.

In the case of both *Trichoderma* and cocopith, demand conditions are largely influenced by the education of farmers and acceptability of new technologies. Factor conditions beneficial to both industries include public and non-governmental support institutions; in the case of *Trichoderma,* those institutions are Bangladeshi, whereas for cocopith, they are U.S. Agency for International Development (USAID). The factor condition that is the largest hindrance to the cocopith industry is weather and land availability, whereas for *Trichoderma* it is infrastructure related to transportation and formal government registration procedures and quality controls. The competition between farmers producing *Trichoderma* themselves, and manufacturers producing it commercially, is an interesting one that may require further research as understanding the characteristics of farmers who use either type of *Trichoderma* might help extension efforts.

Case 3: Nepal

Located between India and China, Nepal is rich in natural resources such as forest, water, and biodiversity. The country's GDP is reported to be $21.13 billion USD (FAO, 2016).[65] Tourism is the largest industry followed by agriculture, which contributes 36% to the GDP. Government spending on agriculture (% total outlay) was around 8.5% in 2014, which increased from 4.9% in 2000. Approximately 66% of the population was employed in agriculture in 2000, a decline from 80% in 1990. Women make up 72.8% of agricultural employment.[66]

Nepal has nine million hectares of harvested area (2014) which has grown by 2 million since 2000. Total area under irrigation is 1.3 million hectares. The country grows a number of fruit and vegetable crops. Some important ones are apple, peach, pear, plum, walnut, orange, lime, lemon, mango, lichi, banana, pineapple, papaya, cucumber, lady's finger, brinjal (eggplant), pumpkin, and several leafy vegetables. Nepal is also famous for orthodox tea, large cardamom, turmeric and ginger.[67] Most Nepalese farmers grow diversified crops in order to hedge against erratic and uncertain weather conditions. Fertilizer usage has drastically increased over the period of 2002-2015. The World Bank recorded an increase of 57.1 kg per hectare in Nepal.[68]

In terms of transportation, the rugged terrain of Nepal poses formidable natural obstacles to road construction. Even where roads are built, many can often be used only seasonally. Road transport remains popular, however, and there is subsidized air service in much of the country that facilitates the transport of both people and goods. Only 76% of the population has access to electricity, which is not always consistent.[69] This poses a challenge for manufacturing in the country, especially of products that require cooler temperatures, such as liquid formulations of *Trichoderma*.

Trichoderma production in Nepal is concentrated between two manufacturers, Agricare and Praramva Biotech, and 11 community-based production facilities. An estimated four companies import

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[65] Country statistics: Nepal. Food and Agriculture Organization of the United Nations. (2016). FAOSTAT statistics database.
[66] Food and Agriculture Organization of the United Nations. (n.d.). Nepal at a glance. Retrieved from: http://www.fao.org/nepal/fao-in-nepal/nepal-at-a-glance/en/
[67] Ibid
[68] World Development Indicators Database-Nepal. (2015). World Bank Group
[69] Ledesma, D. (2017). Infrastructure in Nepal: Gaps between mountains and plains. Retrieved from: https://borgenproject.org/infrastructure-in-nepal/

Trichoderma from India. Researchers interviewed the founder of Agricare, and the three business partners who run Praramva Biotech. They also interviewed one *Trichoderma* importer. Other data collection included five interviews with the owners of small pesticide/farm shops called "Agrovets," and interviews with several Community Business Facilitators (CBFs) who are farmers working with iDE Nepal to train others in IPM techniques and act as middlemen between farmers and Agrovets. All interviews took place in and around the Kathmandu Valley. A large-scale survey of 400 tomato farmers across four regions of Nepal was also conducted through a separate research project looking at the damage related to *Tuta absoluta*, and that survey included several questions about the use of *Trichoderma* and cocopith. Qualitative data was analyzed using the iterative coding process described in the methods section, and quantitative data was analyzed using simple summary statistics. The results are presented according to the Diamond Model framework, with the survey results included under the "demand conditions" section.

Trichoderma

Factor Conditions: The Role of Government:

The Government of Nepal has adopted a number of agricultural policies that have the potential to contribute positively to the growth of the *Trichoderma* industry: organic agriculture is in the five-year strategic plan of the Nepali government and there is a push to produce and sell only vegetables with no pesticide residue. This facilitates an interest among farmers for adopting non-synthetic pesticides to control disease. The *Trichoderma* manufacturers and importers are hopeful that if these policies come to fruition and are enforced, it will be easier to market and sell IPM products, including *Trichoderma*.

Although the formal government policy includes provisions for the promotion of pesticide-free vegetables and organics, this is not commonplace in many markets. Growing organic is more expensive than growing conventionally. One manufacturer stated that having a policy to label organic vs. non-organic would "tremendously change the whole thing." When asked if the sales of *Trichoderma* would increase should this policy be implemented and enforced, he replied "a lot."

Another major challenge for manufacturers is that the government policy governing biopesticide manufacturing and registration is not clear. One biopesticide manufacturer expects that once *Trichoderma* receives a formal registration from the government, sales of *Trichoderma* will increase by at least 25%. He states:

> *"We have no regulations in the Nepal government so that we can register bio-pesticides or microbes as a product. [Conventional pesticide companies] can register by providing research that is done in a foreign country. Considering the Nepalese scenario, there is no policy to provide research to industry. The use of bio-fertilizer is a new thing for the government so there are not*

> *any types of programs or grant programs available to establish in the sector related biofertilizers, biopesticides, bio-insecticides"*

This company sees the lack of government policy as limiting its ability to expand in two ways. First, the lack of government policy hinders awareness about bioproducts. Second, they are unable to export because they must first have the product registered. This lack of formal registration process gives an advantage for importers of *Trichoderma* because there are formal rules and registration procedures for imported bio-pesticide products but not those manufactured in Nepal. The company is lobbying the government to try to change this. They are hopeful that if their lobbying efforts are successful, they will be granted a temporary registration number. The Nepal Agricultural Research Council (NARC) would then conduct trials on two seasons of vegetable production. After two years of retrieving the data, they are hopeful that they will get formal registration. The other biopesticide manufacturer was less optimistic, and said that he could not think of any policies in Nepal that have helped with *Trichoderma* production. One CBF informant echoed this concern, and furthermore stated that no provision to promote local production preferences international production and crowds out local production of *Trichoderma*.

Government subsidies have helped one manufacturer through the vermicompost side of his operation, and also the importer of *Trichoderma*. Eight years ago when the business started, the government gave him a subsidy for two years. Originally, the government was starting to give subsidies on all imported agricultural inputs, but now they are selecting certain ones. Among those selected is *Trichoderma*, cocopith, and plastic trays.

Factor Conditions, Continued:

Nepal was the country with the most obvious presence and influence of the IPM IL and its partners on the adoption of *Trichoderma*. Through iDE Nepal, an IPM IL collaborator, hundreds of farmers throughout Nepal are trained in IPM management techniques, including the use of *Trichoderma*. In 2014, iDE Nepal and the IPM IL hosted a workshop at one of two *Trichoderma* manufacturing facilities. Experts from TNAU led a group of over 40 researchers, NGO representatives, and government officials through a three-day training where they learned about formulation, production, and quality control procedures.

One of the key ways *Trichoderma* awareness grows is through CBFs. These CBFs are farmers who collect orders of *Trichoderma* from their neighbors, in some cases diagnosing problems and recommending *Trichoderma* or other IPM controls. They then purchase *Trichoderma* from local Agrovets and distribute them to farmers. iDE Nepal claims that the practice of purchasing from local Agrovets, rather than directly from manufacturers, helps the local economy and also increases access to

Trichoderma among farmers who may not live in villages served by CBFs. One CBF claims that she serves approximately 400 farmers, and estimates that approximately half use *Trichoderma*.

In addition to iDE Nepal, the biopesticide manufacturers also participate in education through demonstration plots. They demonstrate application via soil treatment, seedling treatment, and foliar spray. They also visit farms and have demonstration plots on those farms. In the demonstration plot, they go through the complete process, from soil application, to seedling, and then transplant. This is important because most farmers will only use bio-pesticides when they see a disease. The demo plots are meant to get farmers to understand that they must apply the bio-pesticide from the beginning so it can complete its life cycle and enter the host, and then it can control the disease.

The generally low education levels of most farmers is a challenge for the *Trichoderma* industry. Though certain applications are straightforward, there are other more complicated application methods. For example, one manufacturer explained when using *Trichoderma* in drip irrigation or as a foliar spray, you have to add carbonyl methyl to get it to stick to the leaves. If you just add *Trichoderma* and water together, it won't be effective.

Agrovets who sell *Trichoderma* claim that very seldom do people come into their shops requesting *Trichoderma*. They claim that only the more educated people use *Trichoderma*. Similarly to the U.S, the more educated farmers grow organically, while farmers who aren't educated don't know about organic products. They prefer a quick result and spray synthetic pesticides.

Demand Conditions:

The primary purchasers of *Trichoderma* in Nepal are farmers. Compared to a recent survey conducted in Bangladesh, which estimates the adoption of *Trichoderma* at between 2-4%, adoption in Nepal is relatively high, at 25%. Adoption in the four regions is as follows: Surket - 27%, Kaski - 24%, Banke - 11%, Lalitpur - 34%. 55% of farmers get their *Trichoderma* from Agrovets, 25% get them from CBFs, 16% use both CBFs and Agrovets, with the rest obtaining *Trichoderma* from a neighbor or relative. Villages that have CBFs have higher rates of *Trichoderma* adoption than non-CBF villages. Though a causal link between the CBF and adoption of *Trichoderma* cannot be determined due to the selection criteria of CBFs (they are, in general, more highly educated and have successful farms, for example, so the farmers served in their villages may have similar characteristics that are highly correlated with a decision to adopt), of the 102 farmers who report using *Trichoderma*, 71 of them live in villages with a CBF.

Despite high observed adoption rates, Agrovets and agrochemical manufacturers remain pessimistic about the adoption of *Trichoderma*, mainly due to quality concerns. Agrovets mentioned that the shelf life of *Trichoderma* is short and sometimes the quality is low. Additionally, the storage of *Trichoderma* at the retailers could be another issue with respect to quality control, because of variable temperature. One *Trichoderma* importer explained that the market for biopesticides is small because farmers are not aware of the technology nor how to utilize it. They explained that it is necessary to go to the farmers and teach them about *Trichoderma*, and grow their confidence in bioproducts.

One *Trichoderma* manufacturer explains how the high discount rate of farmers limits *Trichoderma* sales:

> *"One of the biggest things, fertilizer can have a very quick and fast effect. And the living organism will have a very long, sustainable effect. And the farmers right now are not, in the context of Nepal too, they are not very much commercialized. And they want a quick result because their profitability will matter in 60 days or 30 days...it is very hard for them to commit in the beginning to use the [biopesticide] products so they don't have to use the chemical pesticide."*

One Agrovet spoke about the types of customers who demand *Trichoderma*. During planting season (March and September), he estimates that he sells *Trichoderma* to approximately 250 local farmers, most of them producing organically. He has customers who come in looking specifically for *Trichoderma*, and others who look for advice and *Trichoderma* is recommended to them. Agrovets also attend government and iDE trainings, and access information on the Internet. When asked, Agrovets also stated that they call an agricultural scientist for information, though it was not clear through follow up whether that agricultural scientist was part of a university or the IPM IL team. While the CBF structure through iDE Nepal helps facilitate availability of *Trichoderma*, there is a barrier that not every Agrovet sells it.

In terms of application, farmers surveyed prefer applying *Trichoderma* as a foliar spray, followed by mixing in FYM. 20% of *Trichoderma* adopters use more than one method. A few farmers mix *Trichoderma* with seeds before planting, which was cited as a method taught by farmer facilitators. The powder is preferred over the liquid, with 78% of farmers using powder, 21% using liquid, and 3% using both powder and liquid. The majority of farmers do not know which brand *Trichoderma* they use, with 68% reporting that they do not know. The most popular known brand is Sanjeevi, which is imported from India. 3% know that they use Biocide Trivi (Agricare), and 3% know that they use Praramva *Trichoderma* (Praramva).

CBFs explained the way they teach farmers about application procedures: *Trichoderma* is used at nursery time and at transplanting time when it is mixed together as compost. Sometimes *Trichoderma* is used as a soil treatment one month before transplanting. So, in terms of a typical schedule advised by farmer facilitators: In February, you mix *Trichoderma* with water and drench the soil. In March, it's seedling time. In April, you transplant the seedlings with *Trichoderma* and compost.

Another farmer shares his application procedures:

- Soil application: Mixes 100 kg of regular compost with 1-2 kg of *Trichoderma* 15-20 days before land preparation. Then applies to the soil 2-3 days before transplanting.
- Foliar spray: Uses when he sees wilt and other diseases at evening time. There is no fixed schedule; when he sees the disease, he will apply. When there are hail storms, he will also apply to increase plant health.
- Seed treatment: doesn't recommend seed treatment because it is the wrong temperature. He recommends drenching in nursery production. In temperatures less than 20 degrees, *Trichoderma* won't work.
- Uses chemicals mainly for insects. Uses for disease if it perseveres.

One manufacturer recommends that farmers try to multiply the *Trichoderma* on their own before spraying it by taking a very large jar, adding in a half kg of sugar, and a half kg of yeast together with the *Trichoderma*.

Though the powder is more frequently used than the liquid, most Agrovets and manufacturers prefer the liquid formulation. One Agrovet says that the liquid is more effective than the powder. He advises for crops that are direct sown, farmers use 5ml per 1 liter of water and spray it in the morning or the night, not in the sunlight when plants are still seedlings. He also recommends mixing *Trichoderma* with manure. For crops that are typically started in a nursery, including cauliflower and tomato, the *Trichoderma* should be used in the nursery phase.

Another Agrovet says that he recommends the liquid, but farmers prefer the powder because they can mix it better with manure. He prefers the liquid because it is quick acting and effective. He tells his customers to spray, but they want to mix the powder into compost/manure. Yet another Agrovet claims that interest in the powder formulation is declining rapidly because of quality concerns. He sells only 1/3 of the *Trichoderma* powder he sold two years ago, he thinks because of quality and shelf life. That Agrovet sells the Sanjeevi powder, but previously sold Biocure-F, which is a popular Indian brand of *Trichoderma* from the Stane Company, toured by researchers in the exploratory trip. He claims that he switched to Sanjeevi because it was more effective and less costly. Only 5% of his customers buy *Trichoderma*, he thinks because using the product only makes a small amount of difference due to poor quality. When the *Trichoderma* is of higher quality, he has many repeat and new customers.

Praramva Biotech estimates that the primary users of the liquid *Trichoderma* formulation are large-scale commercial growers who use drip irrigation systems. It is easy for them to add a dose of *Trichoderma* to the irrigation tank itself, which delivers *Trichoderma* directly to the plants. This makes it easier than using a foliar spray. If drip irrigation systems were to become more prevalent, as they have in India, there may be an increase in the sales of the liquid formulation because of the ease of application in a drip irrigation-dependent farm.

When asked about the benefits of *Trichoderma*, many interviewees responded with claims about health. It is good for the health of the soil, and better than synthetic pesticides in terms of health of the farmers applying the product. Many also mentioned the long-term positive health effects of using *Trichoderma*. If farmers use *Trichoderma* over a long period, their soil will be good, and will be free of bad fungus, such as powdery mildew. The good bacteria and fungus in the soil will increase the productivity of the land and help farmers spray less synthetic chemicals. Several farmer facilitators claim that they have seen an increase in yields since adopting *Trichoderma*. One farmer-facilitator has seen a 20% increase in yields since adopting *Trichoderma*, and has seen an increase in the yields of the IPM field school he manages.

Effectiveness of *Trichoderma* is a challenge for demand. One farmer shared that she has not seen a difference in yield since using *Trichoderma*; however, she sprays chemicals less frequently. She claims that the foliar spray works better when it is sunny outside (this runs counter to the scientific protocol, which says that farmers should spray when in the morning or evening, not in the sunshine). When a small amount of disease is present, she sprays with *Trichoderma*. If it doesn't work, she uses chemicals. Another Agrovet explained that only approximately 5% of his customers purchase *Trichoderma* as farmers only see a small difference because at the present time, the *Trichoderma* available is not of quality, so farmers have many problems with it. When the *Trichoderma* is effective, he sees an increase in customers because they purchase it more regularly.

Firm strategy, structure, and rivalry

There are two commercial manufacturers of *Trichoderma* (Agricare and Praramva Biotech) and an estimated four biopesticide importers who purchase biopesticides, including *Trichoderma* powder, from India. Agricare's founder was first introduced to *Trichoderma* at a visit to Ranpur College. This was followed by the IPM IL workshop that took place in Agricare's factory. Praramva Biotech is a partnership between two former biotechnology students and one business student. The importer researchers spoke with has been importing *Trichoderma* for eight years, and was first introduced to it though a web search for biopesticides when searching for new business opportunities. All *Trichoderma* products are sold at the same price. One informant shared that the reason is pricing related to trust. The rate farmers pay should be the same, regardless of the manufacturer. This presents some challenges to manufacturers entering the market who may need to charge higher prices to overcome higher startup costs. The other challenge with this price setting is that it may limit innovation.

Praramva Biotech employs 11 employees full-time including themselves, paying monthly wages in addition to food and lodging. Additional laborers are hired based on demand. Agricare employs 150 individuals, of which 5 are microbiologists trained by Dr. Nakkeeran in producing *Trichoderma* as well as other bioproducts such as *Psuedomonas*. The *Trichoderma* importer employs three people. Average wages for workers at these three companies range from 12,000-15,000 Nepalese rupees per month. Additionally, there are 11 community centers throughout Nepal that produce *Trichoderma*. Each center is staffed by 2 full-time employees, and they are considered poorly resourced.

Both manufacturers and the importer sell other products in addition to *Trichoderma*, with *Trichoderma* making up a small portion of total sales. As a portion of Agricare total sales, *Trichoderma* makes up just 3-4%. The Agricare interviewee claims that if they stopped manufacturing *Trichoderma*, he would only lay off 1-2 people, indicating that the jobs are not dependent on the *Trichoderma* industry. Praramva similarly relies heavily on the more profitable vermicompost side of the business, with *Trichoderma* making up between 6-12% of total product sales. The importer estimates that he sells 500 kg per year with a profit margin of roughly 20%. Sales have remained constant over the last three years with *Trichoderma* making up 3% of annual sales.

Agricare employs a team of marketers to help promote *Trichoderma*. Those marketers work with approximately 5,000 Agrovets across Nepal, of which an estimated 500 sell *Trichoderma*. Relationships with Agrovets include training in application techniques and proper storage procedures. Before selling *Trichoderma* to an Agrovet, Agricare ensures that the Agrovet will have at least 50-60 *Trichoderma* customers. In addition to working through Agrovets, Agricare also promotes *Trichoderma* and other products directly to customers. They use Facebook and YouTube to advertise and demonstrate proper application techniques. They also created a system called Centro-Agricare, which has contact information for 50,000 farmers. Through this system, farmers receive text messages and calls with information about bio-products.

In terms of producing the powder vs. liquid formulation of *Trichoderma*, Agricare shared that in order to stabilize *Trichoderma*, it needs to be mixed with Talc. Calcium carbonate is locally available but the pH is too high. Talc is not readily available in Nepal, so it must be imported from India. The quality of the imported Indian talc is questionable, and considered to be not up to the standard where living organisms such as *Trichoderma* can survive. That is one reason the liquid formulation is preferred.

When comparing locally produced *Trichoderma* versus the Indian imported product, one local manufacturer explained that local *Trichoderma* strains are more tailored to the unique conditions of the country, and thus locally sourced spores are more effective. Furthermore, the *Trichoderma* produced in-country is fresher than the imported *Trichoderma*. One individual interviewed who produces *Trichoderma* at a community center claimed that the only product that works is what is produced fresh locally at the centers. He claimed that he tried Agricare's product once, and it didn't work, citing poor storage facilities.

The Indian product he tried was similarly ineffective. There is no governmental requirement for a viability test with imported products, they simply have to be registered in India.

Similar to Bangladesh, refrigeration and poor road transportation limits the extent to which manufacturers can store and transport the *Trichoderma* produced. One researcher in India remained skeptical of the quality of the Indian export because trucks are often stopped at the border for long periods of time. The importer estimates that it takes two months to get from his supplier in India to Kathmandu, and another four months to offload, which is a total of six months before it reaches the Agrovets. The high temperatures in that truck could degrade the quality of *Trichoderma*, rendering it ineffective. Agricare also acknowledges the difficulty in transporting and storing *Trichoderma*. They strive to get the product to market within 2-3 days of packaging. By producing and sending frequent shipments, they hope that Agrovets will not overstock the *Trichoderma*, which would lead to the *Trichoderma* spending too much time in storage, rendering it ineffective.

As mentioned in the factor conditions section, manufacturers in Nepal experience a similar challenge to those in Bangladesh and Tamil Nadu, in that they are unable to get a proper registration of the product from the government. This limits their ability to export and compete with synthetic pesticide manufacturers.

Cocopith

Over the past 10 years there has been increasing demand for cocopith. Most of the cocopith is imported from India (Gujarat, Delhi, and Kerala, depending on price) because the cocopith produced in Nepal is used for the tea and coffee industries. There are an estimated seven cocopith importers in Nepal who sell two types of cocopith: one with added nutrients and one without. The cocopith importer researchers spoke to has about 18 employees. He first heard about cocopith when he worked in Israel, where both cocopith and *Trichoderma* are popular. In 2010, there was virtually no demand for cocopith, so he imported only 5 kg for his own use, but now the market is increasing, allowing them to import and sell 15-20 tons per year over the past couple years.

He attributes this increase in demand to educating the farmers about the benefits of cocopith and plastic trays. The company holds monthly trainings throughout Nepal for both dealers and farmers, which also helps the company assess the demand for cocopith. He claims that trainings take place through 55 distributers in all 77 districts in Nepal, whenever the dealers can collect enough farmers who need the training. In terms of application, the importers recommend that farmers soak the raw cocopith brick in water overnight and then mix one part cocopith with one part vermicompost and place into the plastic trays. This is different than the method described in Tamil Nadu, which necessitates composting the raw cocopith and adding nutrients (not compost) before placing in plastic trays. While no scientific research has been conducted on the most effective cocopith mixture, farmers and Agrovets report large levels of satisfaction with this method.

The importer mentioned that sales have increased significantly in the last five years and cocopith and seedling trays account for approximately 30% of this importer's total sales. Agricultural importers receive lower taxes from the government to help farmers and the agricultural industry, and this subsidy depends on the specific product that is imported. One barrier referenced was that the trays that are most commonly used for seedling production are not good quality and often melt because of the heat. This challenge was echoed by the farmers as well.

Farmers interviewed attested to the benefits of cocopith frequently. They noted that transplants that were grown in trays with cocopith had higher germination rates, higher survival rates, and less disease. Adoption of cocopith among the regions surveyed is estimated at 11%. Of those, approximately half use plastic trays, and half do not. Similarly, half of those adopters use cocopith with nutrients, and half do not. In interviews, farmers stated that they prefer the cocopith with nutrients, although the cost is higher, so sometimes they buy cocopith without nutrients and add their own. 71% of farmers who use cocopith live in villages with a CBF. In terms of the connection between cocopith and *Trichoderma*, the adoption of both technologies is 6.9%. Of those farmers that use both technologies, 75% live in villages served by a CBF.

One CBF shared that she started using cocopith in trays approximately 2 years ago. Of the 400 farmers in her collective, approximately 150 farmers grow seedlings collectively using cocopith mixed with compost and put into plastic trays. The other 250 members of the group prefer vermicompost in nursery beds. She went on to say that cocopith leads to higher germination rates in the beds, rather than the trays; however, the transplants from the plastic trays grow better.

While most Agrovets said that their cocopith was from India, one claimed that he also received cocopith from Thailand. Cocopith is more frequently used by large-scale commercial nurseries, though researchers were unable to visit any nurseries. For example, one Agrovet shared that he sells mostly to flower nurseries, but also to some vegetable nurseries.

Similar to *Trichoderma*, cocopith is purchased through Agrovets. The same Agrovet referenced above sells more of the non-nutrient variety than the variety with nutrients because of the cost. 4 kg of cocopith without micronutrients costs 80 rupees, and the same quantity with micronutrients is 150 rupees. The added value of nutrients presents an important opportunity for cocopith manufacturers in India and Bangladesh to create a value-added product. The cocopith manufacturer in Bangladesh traveled to Nepal and was inspired by the use of cocopith mixed with nutrients. He says that it can be sold for twice as much as normal cocopith, and farmers demand it. The Agrovets in Nepal shared that the nutrient-enriched variety is demanded more by urban gardeners who don't have access to compost and FYM. Praramva Biotech, who produces vermicompost, is interested in experimenting with cocopith to see if they can create a new product. As mentioned earlier, many farmers mix vermicompost with cocopith for seedling mix, so the company is exploring how they might create a seedling mix product. The *Trichoderma* importer is similarly considering starting to import cocopith bricks from Tamil Nadu.

Factor conditions that contribute positively to the *Trichoderma* industry in Nepal include the presence of the IPM IL, connections with scientists from TNAU, and governmental support of organics and vegetables with no synthetic pesticide residue. Factors that inhibit growth include poor infrastructure that makes the storage and transportation of *Trichoderma* challenging. Furthermore, the lack of formal registration procedures for biopesticides inhibits local manufacturer growth domestically and internationally, and favors the import of products from India. The demand for *Trichoderma* and cocopith appears very strong, as evidenced by a high adoption rate. This is influenced by extensive extension education efforts and a genuine interest and focus among the farmers in Nepal for products that contribute to environmental and physical health. For cocopith, the role of cocopith importers in educating Agrovets and consumers is also influential. The high cost of synthetic pesticides in comparison to biopesticides as well as the CBF incentive structure to encourage the sales of *Trichoderma* over synthetics is a positive contributor.

Discussion and Conclusion

Governmental support is critical to the growth of the *Trichoderma* industry. In Tamil Nadu, government subsidies for equipment and facilities increase the number of *Trichoderma* manufacturers, hence increasing competition and encouraging innovation. In all three countries, the formal registration process for *Trichoderma*, especially liquid formulations, remains a challenge. While Tamil Nadu has a formal registration process, the speed at which proper testing can occur, and the high costs of those tests, are a barrier. In Bangladesh, there are reports that synthetic pesticide manufacturers may be hindering the process of biopesticide registration. Manufacturers in Nepal report that there is no way currently to register biopesticides. However, the government support of residue-free vegetables in Nepal is a boon to the *Trichoderma* industry and plays a role in high adoption rates.

Research institutes are another critical factor in the promotion of *Trichoderma*. TNAU is the most advanced of the two research institutes, as they do large-scale research, testing, manufacturing, and extension work to manufacturers. BARI is critical to the manufacture of *Trichoderma* in Bangladesh, as they are the only trusted source of *Trichoderma* spores and provide important extension services to NGOs, which in turn train farmers. The lack of a university research partner in Nepal limits the amount of quality tests and research and development that can be done with respect to *Trichoderma*. However, the manufacturers in those countries have travelled to TNAU and attended lectures by TNAU researchers to learn about manufacturing processes.

Quality control and shelf life is the most frequently cited challenge among pesticide dealers and among manufacturers when they discuss their competition. There is a lack of awareness of proper storage procedures and expiration guidelines. The reported shelf life of *Trichoderma* powder ranged from 6 months to two years, with some interviewees claiming that temperature did not matter, others stating that it must be kept below 20 degrees, and others stating it must be kept at 30 degrees. For liquid formulations, there were similar inconsistencies, with some claiming that liquid *Trichoderma* should remain in cold storage, and others claiming that the liquid was good for up to two years in normal temperatures. When asked which type of *Trichoderma* (liquid or powder) had the longest shelf life, there was no consensus even among researchers and manufacturers.

The explosion of the nursery industry in Tamil Nadu provides an exciting example of the way in which the agricultural sectors in Bangladesh and Nepal, especially among smallholder farmers, could be transformed. Due to climate conditions in Bangladesh, drying and shipping coconut bricks internationally remains a challenge; however, this process is not necessary or even desirable for selling to the local market. Solving the technical problem of drying cocopith together with increasing domestic demand for cocopith via extensive extension efforts to create a vegetable seedling nursery industry could benefit both manufacturers of cocopith and also significantly help environmental cleanup. In Nepal, cocopith is less available locally; however, it is increasing in popularity as a growing medium, and farmers seem excited about learning to use it. The nursery industry in Tamil Nadu provides important employment opportunities for women who would otherwise have less consistent work, so especially in Bangladesh, where women are not typically in charge of family farms, this could boost their household income, leading to downstream benefits for their family.

Finally, the nursery industry provides a critical platform to diffuse *Trichoderma* to farmers. In Tamil Nadu, nursery owners estimate that the majority of farmers now purchase seedlings from a nursery. If nurseries add *Trichoderma* to their growing medium, the adoption rate of *Trichoderma* could reach almost 100% without farmers making complicated and time-consuming decisions about whether or not to adopt the technology. This might also assist manufacturers who can sell their *Trichoderma* directly to nurseries in addition to local agrochemical dealers. While more technologically inclined farmers would still likely apply *Trichoderma* as a foliar spray or through drip irrigation, it would not be necessary for farmers to achieve at least some benefits.

This comparative case study demonstrates the ways in which the benefits of the *Trichoderma* and cocopith industries accrue beyond farmers. There is evidence that hundreds if not thousands of jobs are created by these industries, both by improving employment opportunities for women in "casual labor" jobs, such as those in the nursery industry, and also increasing opportunities for women in science to work in research and development. While the high level of exports of cocopith has a high economic impact in terms of new dollars entering the economy, a greater and more distributed social benefit is through the creation and growth of the nursery industry. In addition to creating jobs for hundreds of women who would otherwise be underemployed in the case of Tamil Nadu, farmers in both Nepal and Tamil Nadu are achieving large-scale gains through increased plant health.

Recommendations

Based on this research, OED provides several recommendations for future areas of research and extension work:

Research:

1. Test and compare different formulations of *Trichoderma*, including Tricho-leachate, Tricho-compost, talc formulations, liquid formulations and other solid forms for both effectiveness and suitability for both manufacturers and farmers.
2. Conduct research on the most effective growing medium using cocopith including proper decomposition and composting procedures, the correct mix and ratio of nutrients and other soilless mediums.
3. Develop and distribute a low-cost technology that allows people with limited education to see whether or not their *Trichoderma* is effective, in cases where degradation may have occurred.
4. Focus subsequent *Trichoderma* studies on non-farming members of the supply chain, including pesticide dealers.
5. For future farmer survey work, gather extensive information on the source of *Trichoderma* and cocopith, application techniques, and perceived efficacy.
6. Conduct research to explore on the economic impacts of the nursery industry, especially in relation to their use of cocopith and *Trichoderma*, and also impact of the adoption of nursery seedlings over direct seeding by farmers. Include a gender component for this research.

Extension

1. Create clear *Trichoderma* application guidelines for all forms of *Trichoderma* that are widely disseminated among IPM partners, and given to pesticide shops.
2. Create and disseminate clear guidelines for *Trichoderma* storage procedures, including temperature and expiration date.

3. Conduct training to pesticide dealers to educate them about proper storage techniques and expiration dates.

4. Nepal and Bangladesh: disseminate and promote the cocopith technology widely (Bangladesh), encouraging the creation and growth of the nascent nursery industry (Bangladesh and Nepal). This should be accompanied by government schemes to defray the cost of nursery infrastructure.

5. Focus extension efforts on nursery owners (Nepal and India) and seedling mix companies (India) to encourage them to all add *Trichoderma* to their seedling mix.

6. Strengthen the supply chain between cocopith manufacturers and the local nursery industry, ensuring low-cost, high quality cocopith is available to local buyers.

7. Encourage the governments of each of the three countries to create an easier way to register biopesticides.

8. Encourage TNAU to test liquid formulations of *Trichoderma* to allow it to be registered, as it is preferred by most farmers due to their use of drip irrigation systems.