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## EL FUTURO DE LA ALIMENTACIÓN Y RETOS DE LA AGRICULTURA PARA EL SIGLO XXI:

*Debates sobre quién, cómo y con qué implicaciones sociales, económicas y ecológicas alimentará el mundo.*

## THE FUTURE OF FOOD AND CHALLENGES FOR AGRICULTURE IN THE 21st CENTURY:

*Debates about who, how and with what social, economic and ecological implications we will feed the world.*

## ELIKADURAREN ETORKIZUNA ETA NEKAZARITZAREN ERRONKAK XXI. MENDERAKO:

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### ***End of the Ox: Undermining Indigenous Agricultural Knowledge in India***

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# End of the Ox: Undermining Indigenous Agricultural Knowledge in India

Glenn Davis Stone

## Abstract

Social scientists have produced a large and fruitful literature analyzing the ecological and economic adaptiveness of “traditional” agrifood production practices. Less well understood are the processes by which farmers are induced to abandon even highly adaptive practices in favor of high-external-input practices. The ongoing abandonment of ox-weeding by Indian cotton farmers provides an instructive case study. Until recently, India’s troubled cotton sector was highly external-input-intensive except for weeding, which relied in part on a highly adaptive ox-based system with conspicuous advantages for resource-poor smallholders that dominate the cotton sector. But herbicide penetration is a particular priority for Monsanto India because a) India’s relatively low herbicide use leaves open enormous potential for market growth, and b) increasing herbicide use cultivates a large client base for the hoped-for release of genetically modified herbicide-tolerant seed. Based on long-term fieldwork in Andhra Pradesh and Telangana, we document the ongoing replacement of ox-weeding by herbicide use; we show the mechanisms by which this is being accomplished; and we identify the factors that render these farmers vulnerable to these mechanisms.

My concern here is with the issues of farmer learning and decision-making. Much of the literature theorizing these processes, influenced by behavioral ecology (e.g., Boyd and Richerson 1985), centers on the processes of *environmental learning* (empirical observation) and *social learning* (emulation). I find this a fruitful framework, and I have used it some of my own work (e.g., Stone 2007; Stone, et al. 2014). But it is also an anti-politics machine: it whisks from view the myriad external (off-farm) entities that intervene in farmer learning and decision-making, always pursuing their own external interests while insisting they are looking out for the farmer.

I have recently developed a theoretical framework that not only includes but foregrounds these external interventions, which I call “didactic learning” (Stone 2016). It is becoming increasingly clear that these processes have been central to each wave of appropriation (Goodman, et al. 1987) by which agriculture is industrialized: farmers do not simply adopt remunerative technologies or follow local custom, but instead are lobbied, taught, dazzled, cajoled, bribed, and arm-twisted by parties that benefit from farmers adopting. In the long run, we often see that the adopted technologies are less adaptive and more problematic than what they replace.

What follows is an ethnographic case study showing how Indian cotton farmers are being persuaded to abandon an old and well-established set of practices with key economic and ecological advantages. What is being abandoned is a system of ox-weeding that is, ironically, the only sustainable aspect of Indian cotton cultivation.

What it is being replaced by is a capital-intensive treadmill technology that will not only open up the market for increasing herbicide use but open a niche for herbicide-tolerant GM seeds in the future.

The case study draws on a forthcoming article in *Journal of Peasant Studies* (Stone and Flachs 2017).

## Introduction

In India, Green Revolution wheat may have led the penetration of industrial agriculture in the 1960's (Cullather 2010), but today cotton is the main driver of capital- and input-intensive farming. Until late in the 20<sup>th</sup> century, most of India's cotton was grown with low external inputs, often using seeds of indigenous cottons. But by the late 1980's a revolution was underway, based on seeds of the more factory-friendly New World cotton. Unique in world cotton production, these new seeds were hybrids, which locked adopters into the seed market. They were also fertilizer- and water-intensive, and required heavy insecticide application since they lacked resistance to Asian pests. The inputs-heavy cotton package was expensive, but promoted by government policies (including rapidly climbing support prices), encouraged by the agro-scientific establishment, and buoyed by favorable markets, it spread rapidly. Many farmers saw early profits; the intractable problems with agroecology and debt would not come until later (Mohanty 2005, Stone 2011a, Kennedy and King 2014, inter alia).

But while doors to purchased inputs – including hybrid seed, fertilizer, irrigation, insecticide, and more recently genetically modified (GM) traits – were being flung open on cotton farms, the door to one key industrial input – herbicide – remained fastened. In Telangana (Figure 1), a relatively poor state in India's cotton belt, the main barrier to herbicide penetration has been a set of ensconced practices we will term “ox-weeding,” based on the trusty ox plow, human labor, and functionally linked planting conventions. This cultivation system is efficient and advantageous for cash-poor farmers. It relies on household labor and work exchange; draft animals that may be owned, rented or borrowed; and simple familiar tools. With respect to cycles of innovation and change, ox-weeding is a stable system in contrast to the technology treadmills discussed below.

Path dependency theory helps to explain how inefficient and sub-optimal technologies, practices, and institutions may prevail and persist by being “locked-in” (Arthur 1989). The cotton ox-weeding system may also be seen as a technological path, locked in by local knowledge and by social institutions with which the technology articulates. But despite distinct farm-level advantages, ox-weeding has come to be seen as increasingly inconvenient to agricultural capital and the developmental state, which view it as a backward path obstructing the penetration of herbicides in the cotton sector. This is a particular priority to these external interests for two reasons. First is the herbicide itself: Indian farmers plant the world's largest area to cotton and buy over \$2.5 billion worth of insecticides yearly, but spend only \$350 million on herbicides (Sapale and Malani 2015). The potential for herbicide market growth is enormous, and industry looks for sales to reach \$800 million by 2019 (Sapale and Malani 2015). The second reason pertains to the opening of a market for GM seeds with herbicide tolerance (HT) traits. HT traits are the biotechnology industry's biggest money maker by far, with 86% of the

world's GM acres containing plants resistant to glyphosate or glufosinate (James 2015) and a new generation of crops resistant to 2,4-D and dicamba now arriving.<sup>1</sup> However the only GM crop now sold in India is Bt cotton, and biotechnologists face significant headwinds in getting HT crops approved for sale, including a Supreme Court technical expert committee that recommended a ban on HT crops. Opening weed management systems to herbicide use improves the eventual market for HT crops and may even enlist farmers as advocates for HT crop approval.

Longitudinal ethnographic research among cotton farmers in Telangana has allowed us to observe the undermining of the established ox-weeding regime to promote herbicide-intensive production.<sup>2</sup> This situation offers an instructive case study in how farmers may be diverted from a seemingly “locked in” technological path to become more “modernized” producers and better customers for products currently on the market (herbicides) and in the pipeline (new GM seeds). We use the trajectory of agro-technological change in Telangana cotton farming to make two significant contributions, both related to path dependency theory.



Figure 1. Map of India, Telangana, and sample villages in Warangal and Medak Districts.

The first contribution concerns technology treadmills, defined here as situations in which use of a technology encourages or necessitates the use of that technology in

<sup>1</sup> This includes 95.7 million acres of HT-only crops and 59.0 million ha. of crops in which the HT trait is stacked with a Bt trait (James 2015). Bt traits, which provide some protection against insects, are discussed below. [Note: these numbers will be checked before publication.]

<sup>2</sup> Fieldwork was conducted between 2000-2015 in the Telangana region of Andhra Pradesh state, which became Telangana State in June 2014. During this time ethnography has been conducted in over a dozen villages in Warangal District, selected to represent variations in soil, caste, and prosperity. Statistics presented here are drawn from five of these villages as shown in Figure 1, for which repeat agricultural household surveys have been administered to random samples stratified on land holdings. Sample sizes ranged from 144-254 households, except for 2009-1010 when sample sizes were only 43-44 and 2015 when sample size was 311. Because our sample includes farmers from diverse castes, irrigated and rainfed farms, and from villages both proximate to cities and in isolated rural areas, we argue that our claims are widely applicable to cotton agriculture in semi-arid India.

increasing and/or ever-changing forms. Agricultural technology is known to offer examples of path dependence and lock-in mechanisms (e.g., Cowan and Gunby 1996) but the treadmill is a key feature of industrial technology penetration in agriculture that has not been appreciated or theorized. Agricultural treadmills are distinctive in that they actually reverse a basic mechanism of technology lock-in because of how agricultural technology interacts with local knowledge and decision-making systems. Whereas Arthur (1989) describes how the benefits of a technology increase by the learning that accompanies its use and David (1985) describes technological lock-ins where the costs of learning skills prohibit change to more efficient practices, agricultural treadmills are plagued by erosion of local knowledge that ironically encourages even more intensive use of the technology.

Second, we use a longitudinal analysis of the ongoing undermining of the ox-plow system to understand the process of instrumental path-breaking by outside interests. Path dependency theory says relatively little about how and why paths are broken, focusing more on how paths emerge and persist. When paths are broken, the cause is usually seen as “exogenous innovations” or “external force or shocks” that transforms existing relationships (David 2001), but such innovations and shocks are generally not instrumental: i.e, intentionally designed to break a dependent path. The few writers who have looked seriously at mechanisms of path breaking (Martin 2010; Martin and Sunley 2006) have not attended to such instrumental path-breaking. Since in our case it is specifically agricultural technologies being targeted by outside actors, we turn to theories of agricultural decision-making to explain how such a path could be broken. Theories of agricultural decision-making have had their own blind spot for instrumental interventions, with most analyses focusing on the apolitical processes of “environmental learning” (basically experimentation and observation) and “social learning” (basically emulation). But recent theoretical writing introduces the process of “didactic learning” whereby farmer decision-making is instrumentally influenced by external parties (Stone 2016). As agricultural didacts characteristically pursue their own interests from positions of relative power, this perspective is a political ecology of agricultural practice. By focusing on the changing ecology of cotton cultivation, we are able to analyze the path being broken, the economics of why it is being broken, and how it is being broken through didactic learning.

Beyond these theoretical aims, this study has practical importance. Indian cotton farmers have struggled with treadmills involving numerous technologies including seeds, insecticides, and most recently a genetic traits. (These separate technology treadmills have their agroecological peculiarities, but share key interactions with farmer decision-making as summarized below.) The future of GM cotton in India is unsure, but if HT seeds make it to market, the result of the path diversion described here is likely to be an herbicide treadmill as well. We believe that such ramifications of the adoption of GM crops needs to be considered in a debate that is too often constructed in myopic terms of “success” or “failure” in the field (see Stone 2011a on shifting focus from the field to larger questions of the farm).

We first provide a brief history of the spread of input-intensive commodity cotton production and the resulting seed and insecticide treadmills. We show that this production regime is marked by deleterious effects on local knowledge and decision-making, as the conditions of technological change have generated a dysfunctional learning environment. We then explore the effects of GM seed and

industry's aspirations for HT seed and herbicide. This section reveals how the ox-weeding system that is being depicted as an impediment to agricultural success is effective and inexpensive for many farmers (recent increases in labor costs notwithstanding).

We then review the situation with herbicide in India, including recent developments in law, labor, and agricultural technology that various parties are capitalizing on to make inroads for herbicide penetration. We look at the interventions to subvert the ox-weeding system, beginning with the seemingly obscure but actually critical detail of seed placement. Seeding arrangements are functionally linked to other moving parts in the cultivation system, and by altering those arrangements didactic learning interventions are leading farmers towards a dependence on a new path towards increasingly capital-intensive agriculture.

Finally we offer comments on the effects of the path breaking on cotton farmers.

### Cotton Input Treadmills and Local Knowledge

Hybrid cotton seed, which is planted on a large scale only in India, was invented at a public agricultural university in Gujarat in the 1970s. Once commercialized, the technology gained a foothold in southern and central India in the 1980s and then spread rapidly in the 1990's (Lalitha, Ramaswami, and Viswanathan 2009; Stone 2011a). The early-adopted seeds were from public agricultural institutions, but during the 1990's these were largely replaced by seeds from private corporations. Reflecting corporate interests, these seeds were input-intensive by design, optimized for response to chemical fertilizer and irrigation. They were largely based on the New World species *Gossypium hirsutum*, more industry-friendly both in production (with better response to inputs) and in output (with a longer staple preferred in thread production) (Prasad 1999). These seeds were also highly vulnerable to India's abundant insect pests, lacking the natural defenses of the indigenous species *Gossypium arboreum*, and so they were tightly bound to the heavy use of insecticides.

The seeds-inputs package comprised a technological path that was quick to be locked in, particularly by knowledge-related mechanisms. The interplay between technology and local knowledge has been described and theorized elsewhere (Stone 2016; Stone 2007; Stone 2011a; Stone et al. 2014) but a summary will be helpful. In agriculture, *skilling* is the ongoing process of farmers developing the ability to perform with a technology (Stone 2007). Skilling results from both environmental learning (assessment of empirical payoff information on specific technologies and practices) and social learning (emulation of others chosen on social criteria). Writers in anthropology and related fields have long stressed the power of environmental learning, with the "experimenting, innovative, adaptive peasant farmer" being commonly taken as the norm (Richards 1989, 20). But (Stone 2016) argues that this perspective obscures how difficult experimentation actually is for practicing farmers and how payoff information may be inaccessible or unreliable, resulting in agricultural deskilling.

Such deskilling occurred in India during the 1990's and early 2000's as the explosive proliferation of private seed companies and seed brands left farmers facing a bewildering array of rapidly changing and often deceptively labeled seeds (Stone 2007; Stone 2011a). Environmental learning was further hampered because yield

variation within each seed exceeded variation between seeds (Stone 2007:83}. Farmers' response to this fraught learning environment served to lock in the high-inputs package, albeit by a different mechanism than described by Arthur (1989) and David (1985). Unable to "skill on" specific seeds, farmers relied on social learning to the point of herd behavior. Detailed longitudinal data on agricultural decision-making show remarkable seed fads with scant link to the properties of the seeds (Stone et al. 2014). Farmers also exhibited a desperate penchant for new seeds, which further encouraged seed producers to bring increasing numbers of brands to market. Farmers often expressed the belief that new seeds were likely superior and that it was advisable to switch to new seeds at least every three years, a demand that seed companies have been happy to oblige, with the number of cotton seed brands in India climbing into the hundreds (GEAC 2012). Even before the introduction of transgenic traits in seeds (below), this was a treadmill, driven by the intersection of institutional aspects of the cotton seed market and farmer responses to deskilling.

The high-input package has also been locked in by an insecticide treadmill, which works somewhat differently than with seeds. With insecticide sprays, short-term payoff information is readily available: the farmer is immediately gratified by the sight of insect corpses. What is inaccessible is payoff information on the hazards of long-term use. Insecticide sprays kill not only insect pests but the insect predators that keep pest populations in check, and phytophagous (plant-eating) pests usually develop resistance much faster than entomophagic (insect-eating) predators (Kranthi and Russell 2009). By the late 1990s, most cotton pests showed resistance to insecticides (Kranthi et al. 2001; Kranthi et al. 2002). But the insecticide treadmill is not simply an entomological phenomenon, even if it is often characterized as such<sup>3</sup>: deleterious effects on the skilling process are key to it. Farmers wind up not only with new chemically-induced pest problems, but problems for which they have no store of local knowledge and practice from which to find remedies. There are two reactions. One is to escalate sprayings, which both exacerbates the ecological problem and runs up debt. Indian cotton fields that had been receiving 2-3 sprayings in the 1970s were receiving over 30 by the early 2000's, with insecticide costs rising to over 50% of all inputs in some cases (Peshin et al. 2008).<sup>4</sup> The second reaction is to seek sprays with new modes of action, which farmers urgently do, providing a strong incentive for industry to develop new insecticides to perpetuate the treadmill. Indian cotton farmers have progressed from organochlorines and organophosphates to carbamates, synthetic pyrethroids, sodium channel blockers, fungal naturalytes, and the transgenic Bt seeds discussed below. Again, constantly operating with sprays with which they have little experience leads to agricultural deskilling and exacerbated treadmill effects: numerous studies have shown that ignorance of agricultural insecticides leads to excessive spraying (Vandeman 1995; Bentley 1989; Tripp, Wijeratne, and Piyadasa 2005; Chen, Huang, and Qiao 2013). In a sense this is the opposite of Integrated Pest Management, the knowledge-intensive alternative to over-reliance on insecticides, in which increased knowledge leads to reduced spraying (Cowan and Gunby 1996, 526-27). Such an insecticide

<sup>3</sup> E.g., "cotton follows the classic 'pesticide treadmill'...namely, once the pests become resistant, even more pesticides will need to be used" (Jin, Bluemling, and Mol 2015, 24).

<sup>4</sup> In this environment, regular pesticide sprays also take on a social value associated with responsible farming – in a 2013 interview, one farmer explained, "you should always seek to produce more than your neighbors. If they spray four times, you have to spray five. That way, you'll always have the best yield."

treadmill reverses the classic lock-in mechanisms in which skills and knowledge accrue to the use of a technology (Arthur 1989; Cowan 1990).

Both the seeds and insecticides show us the importance of the knowledge economy – especially farmer modes of learning and decision-making – in agricultural treadmills. The loss of skill and knowledge that accompanies the replacement of a non-treadmill technology is usually benign. The replacement of draft animals with mechanized vehicles rendered the disappearing skills and knowledge of teamsters and ploughmen obsolete and unneeded. Not so with the seeds and sprays on the farm: farmers badly need to know the performance characteristics of their seeds and effectiveness of their sprays, but they wind up continually (and often desperately) seeking new seeds and sprays with which they have no experience and for which there is little accumulated local wisdom. The trap of decreased skilling, exacerbated insect problems, and increased spraying has been a major factor in India emerging as a global outlier in insecticide use (Figure 2).

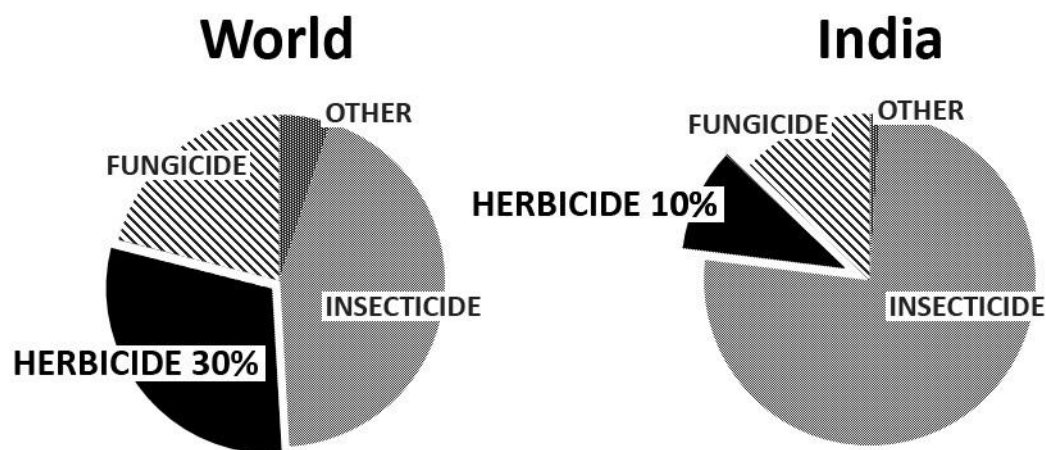


Figure 2 Comparison of pesticide use in India and the world. Source: Aktar, Sengupta, and Chowdhury (2009).

Traveling the insecticide-treadmill path has been especially hazardous for farmers in India, where education levels are low, farms and bank accounts are small, and government safety nets largely non-existent. In Andhra Pradesh, matters came to a head in the 1997-98 season when the intersection of several factors led to tragedy. There had been considerable recent expansion of area planted to cotton and also a steep decline in cotton prices, leaving many poor farmers in an unusually precarious position. That year a perturbation in rainfall and farmers' unfortunate response to it led to a severe outbreak of an erstwhile minor (but increasingly resistant) pest, the cotton leafworm (*Spodoptera litura*) (Reddy and Rao 1998; Armes et al. 1999). Cotton yields in Andhra Pradesh plummeted and several hundred farmers in Warangal District alone killed themselves, commonly by drinking insecticide (Reddy and Rao 1998; Revathi 1998). Although the 1998 calamity was well covered in major U.S. newspapers (Karp 1998; Lambrecht 1998), it was seemingly forgotten later when GMO opponents began to blame the continuing suicides on the GM seeds that were not approved until 2002.

We have observed many organized attempts to break the path of insecticide-intensive cotton production in India, including FAO field schools promoting integrated pest management (IPM), the National Agricultural Technology Project, a



grant-sponsored program for individual farmer advising (Stone 2011b), smaller schemes by numerous rural NGO's, and even commercial schemes offering a premium on organically grown cotton (Peshin et al. 2008; Flachs 2016). But as Cowan and Gunby's (1996) comparison shows, didactic interventions to wean farmers off insecticides can fail spectacularly unless key pieces are in place, such as a successful history of non-chemical management to fall back on. As our brief history showed, the Indian cotton farmers had nothing of the kind, and it is not surprising that none of these interventions has had any sustained success in lowering insecticide use.<sup>5</sup>

### GM Seeds, Treadmills, and Aspirations

The wreckage of the insecticide treadmill provided the niche for the technology Monsanto (and their Indian partner Mahyco) were trying to bring to market: seeds genetically modified for caterpillar resistance, conferred by a Cry gene from the soil bacterium *Bacillus thuringiensis* (hence "Bt cotton"). Bt cotton began field tests around the same time that farmer suicides peaked in 1998, and was approved and released for the 2002 season. At first the technology was available in only a few unpopular seed brands and was taken up by very few farmers, and adoption did not reach 5% until 2005. Meanwhile the insecticide treadmill continued to spin. In Warangal, the most discussed technology in 2002 was not Bt cotton (which almost no one bought), but the new insecticide Tracer<sup>®</sup> (spinosad). Tracer<sup>®</sup> was the most expensive spray yet, but reasonably effective against bollworms which had not yet had a chance to develop resistance. Before Warangal farmers accepted Bt cotton they also began to adopt the spray Avaunt<sup>®</sup> (indoxacarb) as well as new insecticidal seed treatments.<sup>6</sup>

Bt seeds began to gain traction in 2005, after which they spread quickly, claiming 73% of the Indian market by 2008 (Cotton Corporation of India Ltd. 2009; Stone 2015:43). Until 2005, all Bt cotton in India contained the same transformation event: Monsanto's Bollgard<sup>®</sup> containing the Cry1a gene. This technology was only partly effective, and was particularly ineffective against the *Spodoptera* leafworms that wreaked havoc in 1997-8 (Showalter et al. 2009). In 2009 Monsanto announced that another serious caterpillar pest, pink bollworm, was also showing resistance to Bollgard<sup>®</sup>, in the same breath applauding its new Bollgard II<sup>®</sup> technology, which combined two Cry genes (Monsanto 2009b). By 2014 four additional Bt transformation events had been approved and there were over 1300 Bt seed brands in India. Today Bt resistance in pink bollworm is widespread

<sup>5</sup> A pesticide treadmill intervention in the early 2000s temporarily weaned farmers away from excessive sprays and encouraged the use of neem powders, pheromone traps, and other IPM methods. But after a few years most participants abandoned the IPM methods, as the IPM team never checked back with the villagers and then newly introduced Bt cotton seeds controlled pests just as effectively (at first) and with less trouble. However, during that same time period the same farmers began working with university extension services. This time the intervention was mediated through a cooperative agriculture supply store rather than an outside group, meaning that the program would feature a more permanent investment in the community. With this additional social commitment, the cooperative store has a long-term impact on farmer management decisions that short-term interventions fail to replicate.

<sup>6</sup> Recent studies show cotton leafworms have developed resistance to four insecticides (Nandakumar 2016).

(Kurmanath 2015; Buradikatti 2015). Thus GM cotton has emerged as the latest agricultural technology treadmill, made possible by the insecticide treadmill, which was in turn made possible by the seed treadmill. However it is increasingly looking like the already commercialized Bt traits were uniquely low-hanging fruit. There are a few other Cry genes under development, but much of the discussion on dealing with the spread of resistant pests now revolves around pyramided Bt genes and tinkering with refuges (Carrière, Fabrick, and Tabashnik 2016).<sup>7</sup>

Monsanto faces other headwinds in generating revenue with Bt crops, including constant struggles with state authorities seeking to limit its licensing fees. In early May 2015, the Hyderabad High Court, acting under pressure from the Telangana state government, issued an order capping Monsanto's royalties. This move initiated a year of arguments and threats as Telangana, India, and Monsanto fought legal battles over the right of governments to limit licensing fees on GM technology. When the Indian central government slashed Monsanto's royalty fee by 70% in March 2016 (Mulvany 2016), Monsanto threatened to leave India and end new research and development programs. Researchers affiliated with the Central Institute for Cotton Research (CICR) responded that Monsanto's technology was no longer necessary to the Indian cotton industry (Sally 2016), and a Warangal newspaper opined that farmers would have been better off if Bt cotton had never been approved (Sakshi 2016).

The vastly more attractive route to profits is offered by the linked revenue streams of herbicide and HT seeds, where the potential for revenue growth is enormous. For instance Brazil, the world's second biggest GM crop planter after the US (ISAAA 2016), has emerged as the world's second biggest consumer of pesticides (again, after the US; Bajak 2016). In the US, HT crops likely increased herbicide usage by 527 million pounds between 1996-2011 (Benbrook 2012).

Having established its Bt trait as virtually universal in India's cotton fields, Monsanto's stated aim is to open the market for seeds with stacked Bt and HT traits (Monsanto 2014). In 2014 Monsanto got approval to begin field testing of Roundup Ready Flex<sup>®</sup> (RRF) cotton, which combines a Bt trait with glyphosate tolerance. This approval followed years of frustrating regulatory impasse after the Genetic Engineering Approval Committee was disbanded in 2012 during a temporary moratorium on new GM crops. But the timing of the trials of the new seeds awkwardly coincided with a wave of farmer outrage over the spread of insecticide-resistant bollworms, causing political backlash against the company. On the heels of its regulatory victory, Monsanto suffered a new round of criticism as it celebrated herbicide tolerance, a trait that would have no impact on the bollworms.<sup>8</sup> Still herbicide resistance remains atop Monsanto's (and more generally, industry's) wish list and figures prominently in efforts to influence farmer decisions. As with the first GM Bt cotton, HT seeds are already being planted illegally by farmers in anticipation of their official, legal release. The problem for industry and state agrocapi-talism is how to break the path on which most farmers in Warangal are

<sup>7</sup> To reduce the selective evolutionary pressure for Bt resistance in target pests, farmers are required to plant a pest refuge of approximately 20% of the planted area to non-Bt cotton. Some entomologists advocate mandating larger refuges (Carrière, Fabrick, and Tabashnik 2016), but such mandates are universally ignored in India. Monsanto has proposed mixing non-Bt refuge seeds in with the Bt seeds, which would effectively reduce the refugia area to 5% of the field, but has been prevented by approval process mandated by the recently reconstituted Genetic Engineering Appraisal Committee.

<sup>8</sup> In August 2016, Monsanto withdrew its application for approval for RRF seed (Bhardwaj 2016), although as India is their second largest market this was understood to be a bargaining position.

dependent: the interconnected systems of planting and weeding that warrants a closer look.

### Path Breaking and the Political Ecology of Crop Spacing

Until recently, almost all Warangal cotton planting used a system that mixed some ancient technology with modern adjustments and innovation: a hybrid system like so much in Indian agriculture (Gupta 1998). First the field is tilled by an ox-drawn plow. Then the farmer attaches a spacing rake (Telugu: *achchumudu*) with large tines 90-100 centimeters apart (Figure 3) and drives the ox and rake across the entire field to etch a set of parallel lines. The farmer then drives in the perpendicular direction, leaving a crosshatched or tic-tac-toe pattern. A single cotton seed is planted at each intersection (Figure 4). Since this involves marking lines in perpendicular directions, this practice is termed double-lining, or in Telugu *dabba pathi* (literally “box cotton,” referring to the square pattern).



Figure 3. Two different types of *achchumudu* (spacing rakes). In both types, tine spacing is adjustable. Copyright A. Flachs.



Figure 4 “Dabba pathi” double-lined field ready for planting, 2004. Copyright G. Stone.

As the cotton grows, weeding quickly becomes a serious concern. Weeds compete for both water and nutrients and Indian Bt cotton is a nutrient-intensive crop growing where rainfall (and sometimes even irrigation) is unpredictable. Double-lined fields are weeded by two methods. Manual weeding using sickles is done either by hired dayworkers (Telugu: *kuli*) or household members; this method is relatively common early in the season because the young plants are small and vulnerable. But later in the growing season, the preferred method is to attach a weeding rake to the ox and drive it in both (perpendicular) directions, as in the field etching (Figure 5). This ox-weeding is a key feature of double-line cultivation.

Double-line cultivation is effective and time-tested. The technologies for weeding (oxen and implements) are dependable and supported by a body of shared local technical knowledge. Oxen provide dependable traction (even responding to simple commands), add fertility to the field, and make little oxen. Ox-weeding is well adapted to farmers with low and/or unreliable cash flows, and many of the poorest farmers in our sample villages regularly shared animals and field management labor. Ox weeding is cheap: farmers often weed their own field, or hire a single driver and ox to weed an acre field for around Rs 500 (~\$10). The cost of hired *kuli* labor for early weeding was also very low until recently: only Rs 50 (~\$1) per person/day in 2005 in Warangal district. Double-line cultivation is thus locked in by local knowledge, social institutions, and economics. It also locks out reliance on herbicide by rendering it unnecessary and relatively expensive. Until recently, only a handful of farmers in our Warangal study villages used any herbicide on cotton.



Figure 5. Weeding a “dabba pathi” double-lined cotton field, 2005. The grid plant spacing allows the farmer to later plow in a perpendicular direction. Copyright G. Stone.

The challenge for agrocultural is how to break the dependence on double-lining and ox-weeding to open the door to herbicide-based management. Of course this is a perverse reversal of the expected direction of path-breaking (Cowan and Gunby 1996). As noted, didactic attempts to push farmers off an insecticide-intensive path failed; how could farmers be pushed *onto* an herbicide-intensive path? Over the last five years we have witnessed this process, and it begins with the details of seed placement.

Seed spacing may seem an obscure technical detail in farming, but it has often been a pivotal feature in manipulations of agriculture by external parties. As these manipulations are virtually always driven by political, economic or bureaucratic interests that diverge from the farmers', seed spacing is best seen through the lens of political ecology (e.g., Zimmerer and Bassett 2003; McCann 2011; Stone 2016). Seed spacing played a key role in the post WW2 shift to hyper-industrialized farming in the US (Kloppenburg 2004, 118-9), in Mao's micromanagement of agriculture in the Great Leap Forward (Becker 1996, 68-102), and in various colonial schemes for ordering indigenous agriculture (Scott 1998). The change in Warangal involves a new method called single-lining (*salla pathi*) that has been rapidly adopted in recent years. In single-lined fields the conventional grid seeding is replaced by dense seeding in parallel lines. The *achchumudu* spacing rake only etches parallel stripes in one direction, spaced between 40-70 cm apart; seeds are then planted more closely along the lines, like a row crop. Whereas a one-acre double-lined field can be planted almost perfectly with one 450 g pack of seed (approximately 5000 plants), a single-lined field can take several times that much seed; in an extreme version called “high density planting system” (HDPS) now being considered by

leading cotton scientists, an acre may take up to 12 packets (nearly 60,000 plants) in an acre (Venugopalan et al. 2014; Kranthi 2013).

What makes this innovation important to path-breaking is that a single-lined field cannot be properly ox-weeded: the ox can be driven along but not across the rows because the plants are too dense (Figure 6). This leaves too many weeds along the row. Hiring more *kuli* labor late in the season is expensive enough that farmers are turning increasingly to herbicides for *salla pathi* fields, carefully spraying to avoid hitting the cotton plants. Our surveys show that in 2015, 31% of farmers used herbicides on their cotton. The cost to spray an acre was as much as Rs 1000, equivalent to hiring three weeding laborers. Spraying requires more time on the part of the farmer, incurs risk of accidentally spraying one's cotton plants, and delivers less immediately visible effects, but given rising labor costs it is cheaper for farmers who hire labor external to their households.



Figure 6. A “*salla pathi*” single-lined field, 2013. The farmer can only ox-weed in one direction, leaving some weeds along the rows. Copyright A. Flachs.

We first encountered single-lining in 2001, when it was an oddity reported on a single field in our sample villages. By 2005 it was still only used on an estimated 1% of cotton fields. We began collecting systematic data on single-lining in 2012, at which point it still accounted for a minority of fields but was replacing double-lining very rapidly, topping 90% within three years (the adoption curve is significant, as addressed below).

One factor in the sea change in cultivation strategy pertains to legislation affecting agricultural labor costs. A guaranteed workfare program called MGNREGA<sup>9</sup> took effect nationwide in 2008, guaranteeing at least 100 days of work on government-

<sup>9</sup> The Mahatma Gandhi National Rural Employment Guarantee Act.

sponsored village improvement projects during the summer agricultural lull. In Telangana, the law mandated a daily wage of Rs 180 (\$3). The wage increase does not directly affect agricultural labor as the program employs laborers for public works, but the new pay baseline has had spillover effects; by 2015 agricultural labor (including transportation) was typically Rs 200/day in our sample villages. How long these wage effects will last is unclear; some recent writing sees the MGNREGA as “in crisis” (Aggarwal 2016). But higher labor costs have made herbicide use more attractive to some farmers (Kulkarni 2011), and have given the herbicide industry new grounds for touting their products (Saripalli 2014; Monsanto 2014), particularly as a component of the shift to input-intensive single-lining.

But, interestingly, evidence for higher yield and/or profits is equivocal. Controlled research plots show yields to vary significantly depending on the variety planted and its care in the field (Venugopalan et al. 2014; Arunvenkatesh and Rajendran 2013). Anyway there is often a huge gulf between yields achieved under controlled research conditions and actual farm use, and no data were heretofore available on farm conditions. Our own sample of 1007 plantings over four years in five villages allows us to compare actual on-farm yields for double-lined and single-lined fields, finding the frequency distribution of yields to be nearly identical for the two systems (Figure 7). The difference in average yields was not significant at the .05 level.

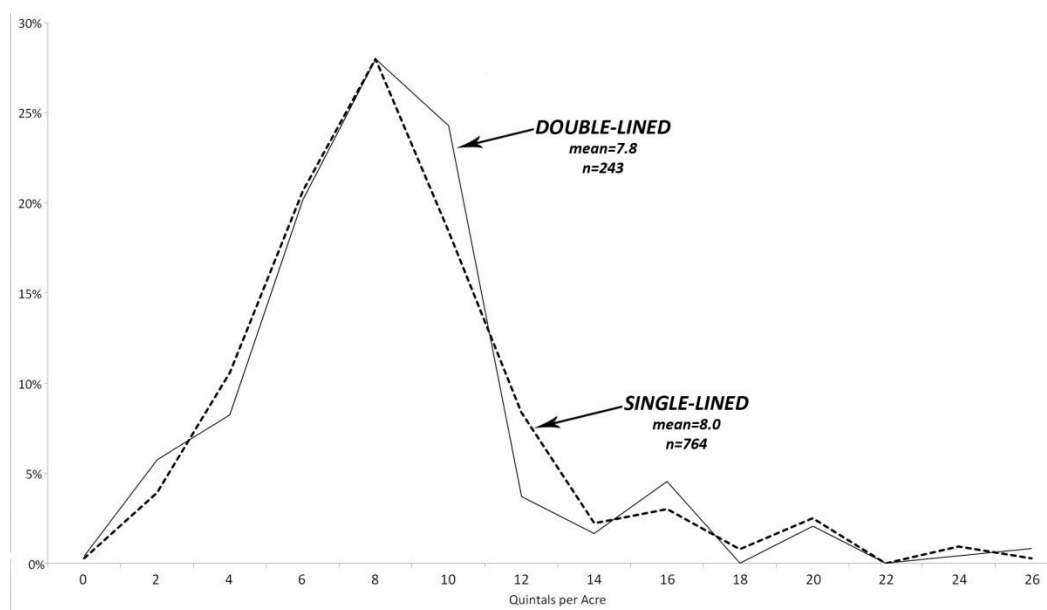


Figure 7. Comparison of cotton yields in double-lined and single-lined fields. Cases from 2012-2015 in five villages are lumped. Difference in means is not significant at .05 level.

Whether single-lining can be demonstrated to offer overall economic advantages is a harder question. We have not conducted a systematic study of partial budgets, and indeed our experience with small farm-level economics in India leaves us decidedly skeptical of the apparent precision and even the veracity of partial budgets for that have been included in some other studies.<sup>10</sup> But over the course of

<sup>10</sup> Many analyses of partial budgets are based on eliciting farmer recall of specific expenses that are not recorded and often remembered neither accurately nor precisely, and farmer responses are rarely checked

more than 300 farmer interviews we have obtained much anecdotal information on typical input costs which can at least provide a rough but realistic estimate of partial budgets within our sample (Table 1).

	Double Lining	Single Lining
Seed	930	1800
Fertilizer	800	1200
Sowing	300	300
Weeding (labor)	800	1000
Weeding (ox plow)	500	500
Weeding (herbicide)	0	1000
Insecticide/Fungicide	1000	1000
Harvesting	1800	3000
Total Costs	6130	9800
Yield (quintal/acre)	7.81	7.96
Proceeds	30,459	31,044
Net	24,329	21,244

*Table 1. Figures are given in rupees per acre. On yield figures, see Figure 7. Input costs are estimates based on anecdotal interview information as discussed in text. Figures on proceeds use a price of Rs 3900, which was typical in our sample villages; it is Rs 100 below the average minimum support price because most farmers sell at the lower market price to avoid the delay in government payment if sold at minimum support price.*

We underscore the imprecision in these estimates, but note that they support our skepticism that empirically observed returns to single-lining are so superior as to explain the sweeping change. It is also important to know that for these farmers, both yields and bottom lines often fluctuate erratically, and the modest but statistically meaningful differences in means touted in many analyses are drowned out by the variation and so are invisible to farmers.

Our earlier findings on the problems of skilling in Telangana cotton production therefore loom large. Longitudinal research has documented the challenges in the information environment, producing over-reliance on social learning with little grounding in environmental learning as described above. Just as this pattern of learning has been a major driver of seed adoptions, it appears to be a key factor in the spread of single-lining. Classic studies of innovation adoption found that adoption often follows a distinctive S-curve which is an ogive of cumulative frequencies of a normal distribution (Rogers 2003); Henrich (2001) shows this to be the expected pattern resulting from social learning, distinct from the different r-

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by any form of triangulation. Most ethnographers know the veracity of such studies to be questionable.



curves produced by adoption based on environmental learning.<sup>11</sup> As Figure 8 shows, the adoption of single-lining is quite close to the S-curve for the years for which we have data, and the early part of the curve could hardly deviate from the S-curve by much. Joined with our analysis of yields and estimates of partial budget effects, it seems a sound inference that single-lining is spreading by emulation rather than environmental learning, just as seed choices have.

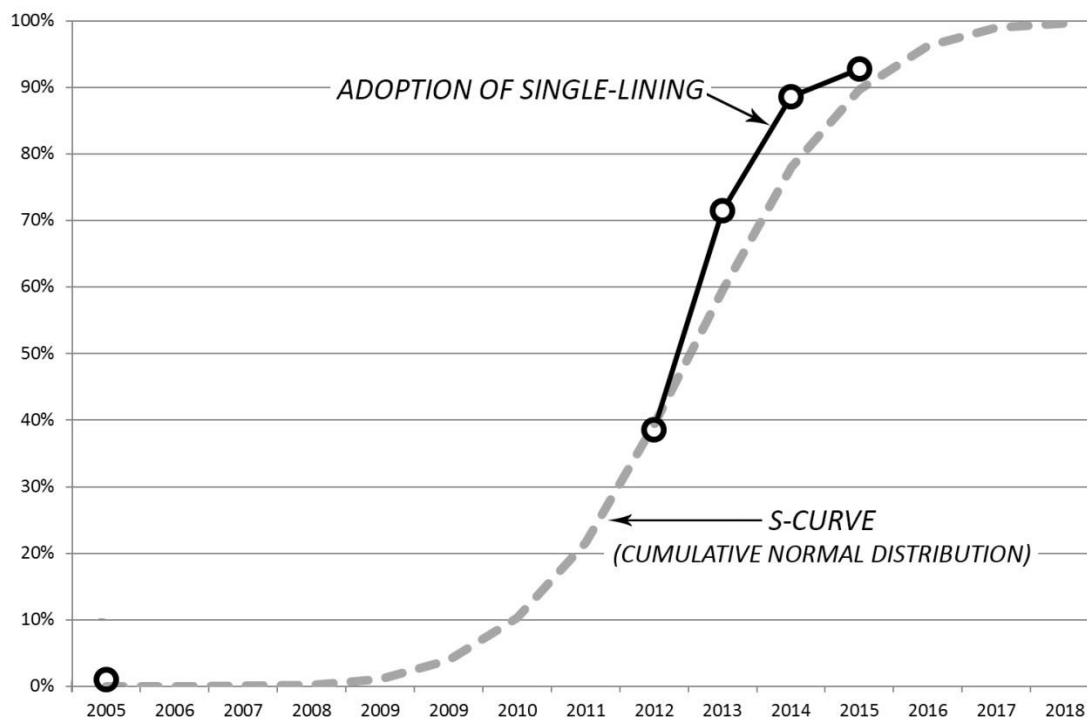


Figure 8. Adoption of single-lining (and abandonment of double-lining) in sample villages. The data point for 2005 is an estimate. The s-curve is a cumulative frequency graph of a normal distribution, the pattern expected when adoption is based on social learning.

However it is much harder to understand the emulative adoption of such a major transformation of cropping strategy than other agricultural decisions. With seed choices, which have been the most striking indicator of herding, at least there is little demonstrable difference in performance and more variation in yield within a seed than between seeds (Stone 2007@83;Flachs 2016). In contrast, double-lining is highly advantageous and “locked-in” by various factors including local knowledge and resource-sharing institutions. To understand how single-lining would spread rapidly via social learning let us consider a new synthesis of farmer decision-making.

### Herbicides and Didactic Learning

A recent synthesis of agricultural decision-making adds to environmental and social learning the process of *didactic* learning, whereby farmers take cues from off-farm parties ( ). Analysts have long been well aware of outside interventions in farmer learning but have given these influences short shrift in explanation of farmer

<sup>11</sup> This is a distillation of Henrich’s argument. He is particularly interested in a form of social learning called biased cultural transmission (BCT). He shows that S-curves of adoption are produced by BCT, or by mixed types of learning where BCT is predominate.

behavior. Indeed, in the seminal study on technology adoption in agriculture -- Ryan and Gross's (1943) classic study of hybrid corn in Iowa -- the seed salesmen and state extension agents who promoted hybrid corn were acknowledged as key sources of information but then ignored in the theory building. Off-farm parties that intentionally endeavor to influence farmer practice are variable, but they "comprise a conceptually coherent category in agricultural knowledge production, distinct from environmental and social learning because they introduce off-farm interests" (, 6).

Agricultural didacts' own interests may, but often don't, align with farmers' interests; but didacts dependably claim for their interests to align. Didactic learning almost always operates where there are significant power differentials, with farmers being lobbied to adopt particular technologies or practices by parties with greater wealth, prestige, and/or authority; therefore there is a political dimension to farmer decision-making that is missed by conventional models of farmer learning and decision-making (e.g., Stone, Flachs, and Diepenbrock 2014; Henrich 2001; McElreath 2004).

Didactic learning can have a surprisingly strong influence on farmers, especially where environmental learning is difficult and where farmers are unable to foresee long-term impacts of technological paths (Stone and Flachs 2014). A classic strategy is for didactic interventions to target farmers likely to be emulated: in other words, didactic learning operates through social learning.

Path-dependency analysts have considered didactic interventions that were intended to break farmers *away* from chemical-dependent paths, which have often met with very limited success (Cowan and Gunby 1996). But in Telangana the challenge for agro-capital is to break farmers' dependence on a non-chemical path, and there has been significant headway as a result of multiple channels of activity. One major effort has aimed at general perceptions, putting a positive face on herbicide-intensive cropping. Many in the agricultural establishment have stressed increased herbicide use as a step towards a modern India (Panchal and Kapoor 2013). Agrochemical industry publications hailing a new Green Revolution argue that backward Indian agriculture needs chemical salvation; the fact that herbicide use accounts for only 16% of chemical inputs is cited as a key area for growth (Sapale and Malani 2015), and cotton industry reports point to herbicide as the way forward for cotton farmers (Saripalli 2014) (see Figure 2). Writers for US-based industry organizations add:

The centuries-old practice of hand weeding fields is no longer sustainable in the modern world. The human drudgery of hand weeding is one of the first tasks readily given up by workers as countries industrialize (Gianessi 2013, 1103).

But no entity stands to gain more than Monsanto, with its leading position on Roundup sales in India and its intent to bring RRF cotton to market. Monsanto explains low herbicide use as a failure in Indian farmer knowledge:

Weeds...are responsible for 30- 60% of the damage to our agriculture yields. But there is very little awareness of this among Indian farmers, while those who are aware, lack knowledge of the appropriate solutions. The penetration level of chemical herbicides

is also very low, ranging from 17% in rice to less than 1% in maize” (Monsanto India 2000).

Thus Indian farmers, hailed as astute evaluators of technology when they adopted GM seeds (Stone 2007), are cast as slack-jawed cretins oblivious to weeds and stumped by weed removal. Monsanto’s endeavors to remedy this lack of knowledge have included farmer field schools and demonstrations of herbicide use. Beginning with 500 farmer programs in 2007, Monsanto India targeted a range of farmers through an herbicide research program (Monsanto 2009a). They also conducted more than 10,000 farm demonstrations directed at small and large farmers in 2012 to raise awareness of Roundup® and discourage knockoff products (Monsanto Company 2012, 15). These efforts build on Monsanto’s didactic activities since the late 1990’s. For instance, in Andhra Pradesh the Meekosam Project placed Monsanto employees in villages to demonstrate products and promote hybrid seeds and chemical inputs (Glover 2007). At the same time that these efforts attempt to reach wide numbers of farmers, they also work through social learning by their explicit policy of recruiting “progressive” farmers who might then be emulated by “slow adopters” (Glover 2007, 68).

Various other parts of the Indian agricultural establishment have been active in striving to break the double-lining/ox-weeding path. The government planning commission lauds the increasing use of chemical inputs as a means to grow industrial production and modernize agriculture (Government of India Planning Commission 2013). The lead cotton researchers in the ANGRAU agricultural university<sup>12</sup> extension office in Warangal, which serves as a resource to local farmers, not only recommend single-lining to farmers, but extol the virtues of the extreme HDPS version of it. Extension services connected to the major agricultural university in Hyderabad (where a small contingent promoting sustainable methods is overshadowed by a large majority promoting industrial inputs) enthusiastically promote single-lining. In Figure 9, a poster at the Warangal Agricultural Research Station (the key ANGRAU extension office for Warangal district farmers) entices farmers to switch to single-lining with a promise of 25-40% higher yield.<sup>13</sup> These efforts again show didactic learning initiatives designed to manipulate social learning: extension agents are much more inclined to interact with prosperous and well-educated farmers who are admired and often emulated by less well-off farmers.

<sup>12</sup> Acharya N. G. Ranga Agricultural University.

<sup>13</sup> Agricultural extension reports also strike a defensive, nationalistic tone when stressing India’s need to increase yield, pointing out relatively low yields per acre (tied in these reports to inefficient non-chemical, low-tech agriculture), especially compared to China (Bagla and Stone 2012).

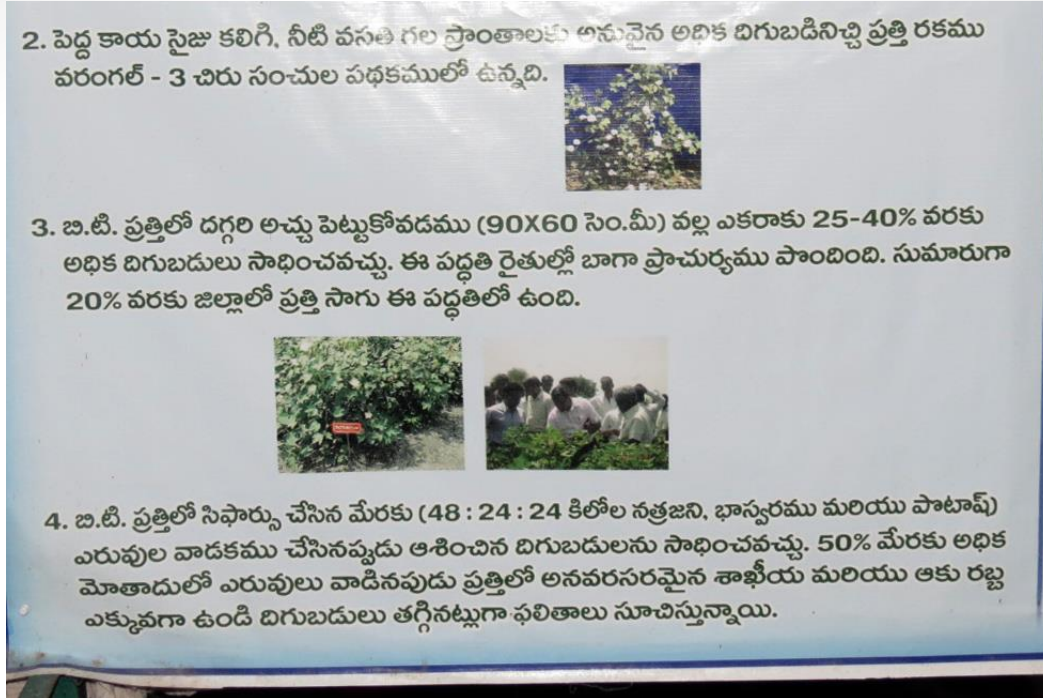


Figure 9. Telugu poster at Warangal Agricultural Research station. Point 3 translates to: "When farmers use the crop spacer in Bt cotton to maintain a distance of (90x60 cm) they can get 25-40% greater production per acre. By using this method many farmers are getting a good yield."

Input shop owners, who have become prominent agents of didactic learning in cotton production, also play a role in the rise of single-lining. Many farmers readily accept advice from vendors on cotton, although not in other crops like rice, which lacks cotton's treadmills. Farmers accept this advice, even though they know perfectly well that the shops stand to profit from seed and herbicide sales. Shopkeepers have little or no technical training, but they are accessible and they always make time for farmers. Farmers have been taking shopkeeper recommendations on cotton seed choices for many years (Stone 2007:97), and farmers even bring samples of their plants to Warangal city shopkeepers to inspect and diagnose (Figure 10). By 2013, shopkeepers were mentioning (and farmers were asking about) seed spacing, although their advice was inconsistent. However by 2016, shopkeepers were consistently advising farmers to follow the dense cropping strategy. "The suggestion comes directly from the scientists," one shopkeeper told us and his customers; double-lining was a "dying trend" another told us, adding that he instructs farmers to plant cotton at higher densities in accordance with sales representatives from seed companies.



Figure 10. Didactic learning from shopkeeper. A farmer shows samples of his crop to a Warangal City shopkeeper and asks advice on products. Copyright A. Flachs.

To observers of Indian cotton farmers and the challenging environments in which they work, the traction these didactic projects gain on farmer decisions is not overly surprising. Despite the claims that input-adopting farmers are "excellent businessmen who aren't persuaded by anything or anybody" (Fumento 2003, 277), decision-making in Telangana cotton cultivation is informed by dangerously little environmental learning. The signs indicate fairly strongly that the spread of single-lining is driven mainly by didactic learning, operating both directly on farmers and through manipulation of other modes of learning.

### The Path Ahead

One of the benefits of the path dependency perspective is that it can help to explain not only specific developments, but trajectories of change. As we observe the ongoing campaigns to re-route the path of cotton cultivation, it is important to consider what future trajectories may hold. Of course this is a question of keen interest to the farmers themselves, but as our survey of the history of treadmills indicates, Indian cotton farmers have an unfortunate record of struggling to see around the next bend. As Krueger (1996) points out, even when it comes to industry leaders, it may be questionable "how well the representatives of the various interest groups [know] their own self-interests." Several future developments seem likely enough to us to warrant mention.

Due to their sheer numbers, farmers are a potent political constituency in India. By clamoring (or being made to appear to clamor) for a technology or policy, farmers can exert considerable pressure on regulators. Bt cotton was in regulatory limbo in 2001 when the story broke that Gujarati farmers were planting illegal Bt seeds; this led to professed fury by Monsanto's Indian partner from whom the trait had been lifted (Jayaraman 2001), but Bt cotton was also approved for release soon after. As farmers continue to shift to single-lining and so increasingly need herbicides that are awkward to use with currently available cottons, they are being transformed into advocates for the HT seeds that Monsanto wants to bring to market. One prediction therefore is that the pendulum will swing towards approval of a technology that the farmers appear to want and need, largely as a result of successful didactic learning initiatives.

As our discussion of the MGNREGA indicates, farmers who have already adopted single-lining will likely find that adoption of herbicide will offer some savings in labor costs, at least with the current configuration of the MGNREGA. This in turn is likely to produce positive feedback to a seeding system that would otherwise not be clearly advantageous, helping to institute the new high-input path and ensuring ongoing revenue flows from herbicide sales. The benefits to state and agrocapi-talism are clear: farmers producing more overall commodity products with a higher investment in seeds and chemicals create an industrial demand for displaced farm labor and a more industrialized economy.

The benefits to the farmers themselves are more mixed. The double-lining / ox-weeding system is being replaced by a much less stable system that is almost certain to lead to new technology treadmills. Mid-century U.S. cotton farmers switched to chemical-intensive methods due to initial profits and government encouragement, only to encounter disaster as sprays lost effectiveness (Cowan and Gunby 1996, 534-35). Herbicide resistance has emerged wherever HT crops have been introduced (Powles 2008; Benbrook 2012), and problems have been particularly intractable with cotton. In the U.S., the advanced industrial agricultural system often cited as a goal by Indian agrocapi-talists (Sapale and Malani 2015; Saripalli 2014) has created superweeds in its cotton fields after 20 years of planting HT seeds. Herbicide-resistant Palmer amaranth, for instance, has been spreading in the US cotton belt for over a decade (Culpepper et al. 2006) and is putting cotton farmers out of business (Gallant 2013). The treadmill there has turned to multi-herbicide resistant seeds, with Monsanto insisting that "These weed management solutions will provide farmers with more consistent, flexible control of tough-to-manage broadleaf weeds". But

others think the benefits will at best be short-lived. Weeds may soon become resistant to the new herbicide mixtures, resulting in new generations of ever-more-intractable weeds that will need to be controlled with yet more herbicides (Keim 2015).

The herbicide treadmill will likely encourage a new transgenic treadmill (Binimelis, Pengue, and Monterroso 2009), as farmers are positioned as obligate customers for not only a procession of traits for insects but for herbicide tolerance. However, whereas the treadmill for insecticidal transgenic technologies can turn for many revolutions by using various Cry genes, the development of new herbicidal transgenics comes to an end much more quickly. Only one gene is known to confer glyphosate resistance, which is why the new herbicidal transgenics simply add

resistance to different herbicides like 2,4-D and dicamba (Benbrook 2012). What the farmer will do when the ox plow has been retired and the weeds are resistant to herbicide is unknown.

Treadmills have strong implications for local knowledge. Condescending Monsanto literature notwithstanding, farmers for whom environmental learning is not obstructed have considerable knowledge about weeds and their management (Tripp 2006); the various forms of ox weeding were in use centuries before they were adapted to use in the double-lining cotton system. But just as cotton farmers are ill-equipped to manage the problem of pest-prone seeds, spray-resistant pests and decimated predator populations, they will be severely challenged by the nexus of herbicide resistant weeds, expensive *kuli* labor, and single-lined fields where ox-plowing does not work. This has to be a serious cause of concern. Industrial cotton farming has managed to splutter along in India for close to three decades despite the pernicious effects of its treadmills, but the history of cotton farming is littered with catastrophic collapses (see for instance Cowan and Gunby 1996, on Mexico; Castella et al. 1999, on Thailand), and an understanding of the underlying dynamics is vital.

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