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Field *versus* Farm in Warangal: Bt Cotton, Higher Yields, and Larger Questions

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Summary. — A longitudinal anthropological study of cotton farming in Warangal District of Andhra Pradesh, India, compares a group of villages before and after adoption of Bt cotton. It distinguishes "field-level" and "farm-level" impacts. During this five-year period yields rose by 18% overall, with greater increases among poor farmers with the least access to information. Insecticide sprayings dropped by 55%, although predation by non-target pests was rising. However shifting from the field to the historically-situated context of the farm recasts insect attacks as a symptom of larger problems in agricultural decision-making. Bt cotton's opponents have failed to recognize real benefits at the field level, while its backers have failed to recognize systemic problems that Bt cotton may exacerbate.

Key words — biotechnology, agriculture, cotton, indigenous knowledge, India

1. INTRODUCTION

The movement of genetically modified crops into the developing world continues to be a matter of widespread interest and some controversy. This movement has been led by Bt cotton, which incorporates one or more insecticide-producing *Cry* genes from the soil bacterium *Bacillus thuringiensis*. India is a particularly closely-watched frontier for this crop. India is by far the world's largest cotton planter but its cotton sector is one of the world's most troubled, ranking 70th in yields and infamous for farmer suicide (Gruère, Mehta-Bhatt, & Sengupta, 2008). The most apparent problem in its fields—at least in the early 2000's when Bt cotton was approved—was predation by Lepidopteran bollworms, precisely the pests for which Bt crops were developed. Therefore the potential for a dramatic impact seemed great. India has also played a key role in the struggle over public relations and discourse (Stone, 2002b): it is an iconic site for external technological intervention in agriculture, and home to a strong NGO sector that has contested the new technological regime at every step (Herring, 2006, 2009; Scoones, 2008).

A verdict of resounding success of Bt cotton in India has been announced by many (e.g., Gonsalves, 2007). Numerous studies of field-level performance are now available, often providing measures of central tendency showing positive results: for instance, throughout India, "On average, Bt-adopting farmers realize pesticide reductions of roughly 40%, and yield advantages of 30–40%" (Sadashivappa & Qaim, 2009, p. 172). Yet these studies have several major limitations, most notably selection and cultivation biases: early adopters are not a random group, but a sample biased toward successful farmers, and Bt plots often receive extra care, making synchronic comparisons problematic. There has also been a counter-narrative of agronomic failure and farmer rejection, even including charges that the new seeds are to blame for the farmer suicides (Shiva, 2008). These publications have their own serious problems, often including dubious empirical support.

In fact, the complex set of relationships between the new technology and its users resists such simple narratives. Even when considered from a strictly economic field-level perspective, Bt cotton's impacts are "inconclusive," according to a review of India (and other developing countries) by agricultural economists (Smale, Zambrano, & Cartel, 2006, p. 195). Agronomic impacts documented to date are also quite short-term, and the complex insect ecology in Indian cotton fields has a history of resisting management solutions. But there is also a larger problem that we risk myopia in modelling Indian farm production as a laboratory well suited to isolating impacts of new factors of production on yields and profits (see Busch, Lacy, Burkhardt, & Lacy, 1991, pp. 49–52). Bt cotton is hardly a technology with no impact on cultivation practices, as claimed by some advocates (Wambugu, 1999); it may bring a plethora of changes including new requirements for field management practices, new kinds and rates of technological change, new sources of advertising and lobbying, and new insect population dynamics. These changes may impact time management, machinery use, health, and indigenous knowledge (Brookes & Barfoot, 2009; Stone, 2007a), but such broader and more indirect aspects of technological change remain little studied and poorly understood.

Within India, activists, scholars, and reporters have paid particular attention to Warangal District of Andhra Pradesh, where the debates on suicide by cotton farmers have been centered (Gruère *et al.*, 2008; Kantor, 2008; Shiva & Jafri, 1998; Stone, 2002a, 2002b). Warangal has been called "the most controversial district in India" (Herring, 2008). This paper draws on long-term ethnographic research in Warangal District to make two contributions. It first presents a panel study comparing cotton production in four villages in 2003, which was the last year before farmers began to adopt Bt seed, and 2007, the first year of virtually all Bt seed. This analysis avoids selection and cultivation biases by using comparable samples of farmers before and after adoption of Bt seed. It then develops a broader perspective on technological change in cotton cultivation, based on a distinction between the field and the farm. *Field* studies, in this usage, concern crop performance under growing conditions, key variables being inputs, ecological phenomena, yields, and profits. *Farm* here

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refers to a socio-economic management unit with such parameters as debt and income, access to labor and land and technology, social linkages with other farmers and vendors, and indigenous knowledge. Studies from this perspective can reveal longer-term and broader dynamics. The focus is on two aspects of farm-level dynamics. First is the recent historic context of cotton cultivation in Warangal: these farms are not ahistoric laboratories, but operations that were in the midst of important secular changes in technology use and market interaction when Bt cotton appeared. Second is the impact of Bt cotton on the acquisition and transmission of information. As Smale *et al.* (2009, p. xv) point out, "Biotech crops have particular implications for the transfer of knowledge and the organization of seed supply and related information, as well as the empowerment of farmers and farming communities. These are some of the issues the public demands to hear about." Indigenous knowledge and decision-making have been central concerns in this ethnographic project.

Results show that from the field perspective, the first five years of Bt use in Warangal have brought moderate success in battling an insidious bollworm problem, including increased yields and sharp declines in insecticide use. In recent years, however, crop predation by non-target insects has emerged as a severe problem. From the farm-level view, the outcome is more complex. Using a history of cotton farmers' articulation with agricultural technologies, this paper maintains that the bollworms were only a symptom of a larger problem: a fraught relationship with technology that has had serious negative effects on agricultural decision-making. Field-level gains have been real, but overemphasized; a technology that mitigates an immediate problem in the field may exacerbate the underlying condition that produced the problem in the first place.

2. RESEARCH ON BT COTTON IN INDIA

Field-level studies of Bt cotton in India now number in the dozens and reviews of this literature are provided by Smale *et al.* (2006) and Smale *et al.* (2009). Smale *et al.* (2006, p. 195, 2009, p. 21) find the results in India to be "inconclusive," citing heterogeneity in physical, social, and economic environments.[1] The clear majority of studies by economists do reveal advantages in cotton yield, and often in pesticide usage, for Bt cotton, but there are several reasons for agreeing that the results to date are inconclusive.

One issue is that measures of central tendency obscure the enormous variability across time and space (Qaim, Subramanian, Naik, & Zilberman, 2006; Smale *et al.*, 2006). Consider the major cotton-producing states (Gruère *et al.*, 2008 especially Fig. 9): yields in Gujarat have surged from below the national average before Bt cotton to leading the country by 2005, while yields in Madhya Pradesh have decreased since Bt arrived.[2] Within sub-state units such as the district or mandal, villages vary greatly in prosperity, access to information, and other factors affecting use of new technologies, which may help explain cases like Maharashtra where studies show a "complex, confusing picture of farmers' spraying behaviour and a startling degree of variability in their cotton output" (Bennett, Kambhampati, Morse, & Ismael, 2006; Glover, 2009, p. 16). It is doubtful that there is any such thing as a "typical cotton growing village" (Subramanian & Qaim, 2009, p. 256) in India.

Research to date has also been overwhelmingly focused on brief periods. India first approved Bt cotton in 2002 and most studies focus on the small populations of early adopters that year and the next: Bennett, Ismael, Kambhampati, and Morse (2004), Bennett *et al.* (2006), Qaim *et al.* (2006), and Orphal (2005) cover 2002–03, while Naik, Qaim, Subramanian, and Zilberman (2005) and Morse, Bennett, and Ismael (2007) cover 2003.[3] Only Sadashivappa and Qaim (2009) present panel data spanning five years, aggregating results from four states. Moreover, none of these studies contextualize the study years in important secular trends in cotton cultivation.

Another persistent problem has been selection bias. Early adopters are known to be a sample biased towards successful farmers (Crost, Shankar, Bennett, & Morse, 2007). Morse *et al.* (2007, Table 3) found Bt-adopters on average to own 58% more land and 75% more non-land assets; Sadashivappa and Qaim (2009, p. 175) found Bt adopters to own up to 36% more land. Lalitha *et al.* (2009, Table 7.6) found Bt-adopters to be not only richer in land, but better educated and more diversified. Morse *et al.* (2007) showed Bt-adopters to be more effective farmers by comparing the *non*-Bt fields of adopters (i.e., farmers who planted both types) with the fields of non-adopters; they found the adopters' conventional fields produced 29–43% more than the other conventional fields. Research to date has very rarely controlled for this bias, and many studies fail to even specify how their samples were drawn (e.g., Barwale, Gadwal, Zehr, & Zehr, 2004; Sahai & Rahman, 2003). The problem is key because almost all studies have focused on the years immediately following the introduction of Bt cotton, when yield differences mainly reflect the agricultural prowess of a biased group of early adopters (and also reflect how this group happened to fare their first time trying a new technology). Crost *et al.* (2007, p. 34) found that in "cross-sectional analysis of the type used in most of the previous studies on Bt cotton, more than half of the observed yield effects would be due to self-selection effects."[4] Two studies have attempted to control for selection bias by comparing Bt and conventional yields for farmers who planted both. Morse *et al.* (2007) found Bt fields in Maharashtra to outyield conventional fields by 43% in 2002 and 27% in 2003; Sadashivappa and Qaim (2009) found Bt yield advantages of 24–58% in a 4-state sample.

A related problem is bias in cultivation practices: prior to the institution of price caps in some states in 2006, Bt seeds cost four times as much as conventional seeds, and would have been planted in the fields with best irrigation and then benefited from unusual care and expense. This accords with the fact that adopters spent *more* on bollworm sprays for their Bt plots than for their conventional plots (Morse *et al.*, 2007, Table 4). In Warangal I have seen many cases of farmers lavishing extra resources and attention on their Bt fields.

Smale *et al.* (2006) also point out that a very small number of scholars have written almost all of the peer-reviewed literature on Bt cotton. Some may also be further discomfited by the fact that several of the studies showing superior field performance by Bt cotton were sponsored by Monsanto (Sheridan, 2009), used data collected by Monsanto's partner, Mahyco (Bennett *et al.*, 2006; Qaim & Zilberman, 2003), or were authored by employees of Mahyco (Barwale *et al.*, 2004).

Much of the literature from NGO's, which routinely reports problems with Bt cotton cultivation, is more problematic yet. The most noted studies finding Bt cotton to have performed poorly in Andhra Pradesh were sponsored by a Hyderabad-based NGO that has campaigned against the technology (Qayum & Sakkhari, 2004, 2005).[5] The most prolific contributor to India's anti-GMO literature has been Vandana Shiva, who has raised useful questions about the political economy of Bt cotton (Shiva, 2005; Shiva & Jafri, 1998) but whose organization has also produced dubious empirical studies of Bt cotton (e.g., Jalees, 2008) and poorly supported charges of the cotton causing suicide

(Shiva, 2008). Most contributions from NGO's, including their empirical field-level studies, do not appear in peer-reviewed forums but seek legitimacy through other mechanisms (Herring, 2009, p. 19).

In some cases there may be grounds for concern over data veracity. Studies by economists and NGO's alike have expected readers to take farmer-collected data at face value without identifying fieldwork practices used to ensure data validity. In many situations it is naïve to expect candor and accuracy in farmer responses. In Gujarat, for instance, use of illegal Bt seeds has been widespread (Herring, 2007; Stone, 2007b), and in some situations farmers may stand to be recompensed if they convince authorities that their seeds failed; either factor would militate against complete candor. In other situations farmers may be confused or forgetful about what they planted or harvested, particularly when farmers jump from seed to seed (as described below).

But the larger weakness in the extant literature is its neglect of the sociocultural context of Bt cotton adoption and use. Smale *et al.* (2006) conclude that "institutional and political context, which is mutable and often ignored, shapes economic impacts, especially over the longer-term. Most often, the contextual factors that influence whether a new variety succeeds or fails are more critical than whether yield advantages can be demonstrated in on-farm trials." Gruère *et al.* (2008) also point to the importance of how Bt cotton "was introduced, sold, and used" rather than the technology itself. The broader farm-level contexts that affect and are affected by the new technological regime in India are highly varied and poorly understood. Subramanian and Qaim (2009) simulate village-wide economic effects of Bt cotton adoption with a micro-social accounting matrix. Among the few studies of sociocultural context are Shah's (2005) analysis of the spread of Bt cotton in Gujarat and Stone's work in Andhra Pradesh (2005, 2007a, 2007b), discussed below. Writings on the possible linkage between Bt cotton and farmer suicide are, in a sense, addressing farm-level impacts. Biotechnology opponents linked GM seeds with farmer suicide even before the seeds were used in India (Christian Aid, 2000; Shiva & Jafri, 1998) and activists continue to make this case (Shiva, 2008), despite a lack of empirical support (Gruère *et al.*, 2008).

In sum, a growing body of literature on Bt cotton in India tends to indicate positive impacts in the field, including raised yields and lowered pesticide applications. However, it reveals enormous variability in impacts, which is often obscured by the attention to average yields. Moreover, it relies heavily on short-term results, and suffers from selection and cultivation biases that make it difficult to isolate effects of the new technology. But more important than these shortcomings is that research to date has focused almost exclusively on "field-level" performance while neglecting "farm-level" issues.

3. THE WARANGAL COTTON STUDY

Findings reported here were collected as part of an ethnographic research project that involved 60 weeks of fieldwork in Warangal District between spring 2000 and summer 2008. A central concern of this research has been farm-level changes associated with technological change, including farmer knowledge, management practices, and decision-making.

Several household/agricultural censuses have been conducted, augmented by extensive interviews. Censuses elicited information on household economics, agricultural inputs including seed choices, irrigation, and pesticides; and yields. Design and implementation of censuses reported here benefited from investigators' experience with local farmers. [6] All census instruments and procedures were carefully pre-tested and adjusted for farmers' length and accuracy of recall as well as candor on various topics.

This study reports on four villages selected to reflect several axes of variability, including soil type, relative commitment to cotton cultivation, prosperity, ethnic/caste composition, and

Figure 1. *Map of India and Warangal District, Andhra Pradesh.*

Table 1. *Characteristics of study villages. Information connectivity is explained in the text; higher scores indicate more access to information*

	Population	Mean acres planted 2003	% Planted to cotton, 2003	Black cotton soil%	Information connectivity	Ethnic makeup
Gudeppad	1,100	4.8	59	High	3.4	Mixed indigenous
Kalleda	3,000	4.4	16	Low	2.7	Mixed indigenous
Ravuru	800	3.9	28	Low	1.8	Mainly tribal
Saireddypally	1,500	6.5	35	Mod	4.2	Mainly Kamma

Table 2. *Cotton yields in quintals (100 kg) per ha. Yields are generally comparable to other figures derived from fieldwork (e.g., Dev & Rao, 2007; Morse et al., 2007; Sadashivappa & Qaim, 2009) but higher than official figures which are based on pure lint. The 2003 figures exclude five Bt planters, all from Saireddypally, whose yields were actually lower than those from conventional seed in this village (23.5 vs. 24.8 quintals/ha). If these cases are included in the grand totals, the mean yield rises from 19.7 to 19.8, the percentage increase drops from 18.0% to 17.5%, and there are no changes in statistical significance*

Village	2003 (all conventional)			2007 (all Bt)			Percentage increase (%)	Significance (2-tailed *t* test)
	Mean	sd	*n*	Mean	sd	*n*		
Gudeppad	22.8	6.1	145	30.4	4.2	59	33.6	<.01
Kallada	11.1	3.9	37	17.2	5.3	15	54.6	<.01
Ravuru	11.4	6.2	30	18.3	5.5	59	60.1	<.01
Saireddypally	24.8	9.1	26	22.4	6.5	48	−9.7	.18
Total	19.7	8.2	238	23.3	7.5	181	18.0	<.01

information connectivity (Fig. 1). To measure information connectivity, the frequency of radio listening, newspaper reading, TV watching, and watching agricultural-extension programs were rated on a scale of never-sometimes-frequently and then combined in a connectedness score.

Village characteristics are summarized in Table 1. Gudeppad is a village of around 1100 in an area with a relatively high percentage of "black cotton soil" that is generally regarded as suited to cotton cultivation. This area also has the highest percentage of land planted to cotton in Warangal; indeed the heavy reliance on cotton has left the area vulnerable to downturns in the cotton market, which may help explain why it has been plagued with Warangal's highest rate of farmer suicide (Reddy & Rao, 1998). Gudeppad has a largely indigenous non-tribal population with a range of castes represented.

Kalleda and Ravuru are in a generally poorer area, with little black cotton soil and a lower commitment to cotton cultivation. Kalleda, with a population of around 3,000, is similar to Gudeppad in ethnic and caste composition but information connectivity is lower. In Ravuru, with a population around 800, the population is mostly tribal (Banjara, or "Lambadi"), with very low levels of education and poor access to information sources.

Saireddypally has a population around 1500 and a moderate percentage of black cotton soils. Its population is dominated by Andhra (mostly Kamma caste) farmers who immigrated from coastal areas several decades ago. These groups tend to be prosperous, educated, and well connected to information sources.

Rather than adding another case to the roster of within-year comparisons of Bt and conventional seed, with their inherent biases as noted, a panel study will compare cotton yields and pesticide use for entire villages before and after Bt adoption. Production data on the 2003 season, obtained in summer-fall 2004, provide a pre-Bt baseline: of 243 cotton seed purchases made by 144 households, only 5 (2.1%) were for Bt seed, and these Bt planters have been excluded from the analysis. (This obviously introduces a selection bias, but the effect is miniscule, as shown in Table 2.)

Within each village random samples of farm households were drawn from the government's 1996 Multi-Purpose Household Survey, which lists all households in the district along with socio-economic variables including land ownership. In each village households were ranked on land ownership and divided into terciles (landless households were excluded as they rarely plant cotton). Households within each tercile were randomized and sampled equally.

In summer 2008 a census elicited data on 2007 cotton production and pest management in the same four villages. Households from 2004 were re-censused when possible; 44% of the 2008 census were re-censuses, and when the individuals were unavailable other households were added from the same stratified random list. Since there were no unusual changes in the farmer communities during this time, this panel study compares what is essentially the same population at two points in time, with almost half of the cases being the same farmers.

The 2007 season marked the first time virtually all farms in the sample planted exclusively Bt cotton. In 2007, most input shops stocked little if any non-Bt cotton seed, and no farmers in the sample reported with confidence that they had planted any non-Bt seed in 2007. In some cases farmers said they were not sure if they had bought Bt seed or not; farmers often buy seeds that others are buying without knowing much about them (the significance of which is discussed below). Therefore it is impossible to specify how many packs of non-Bt seed were bought, but we can be certain that the number is vanishingly small. By 2008, I believe the number to be zero: all of the eight input shops I interviewed in Warangal City and four villages had *only* Bt cotton, and no vendors or farmers knew where one could find a box of non-Bt seed. Most people had stopped even identifying Bt cotton as such. (In comparison to the Warangal sample villages' 2003 and 2007 adoption rates of 2.1% and 100%, India-wide rates are reported to have been 1.2% and 65.1% (Sadashivappa & Qaim, 2009, p. 173).)

(a) *Cotton yields*

Table 2 shows that from 2003 to 2007, cotton yields rose 18% across the sample villages. Villages with low pre-Bt yield saw the greatest yield increase with Bt seeds, with dramatic increases in Ravuru and Kalleda, a moderate increase in Gudeppad, and a small but statistically insignificant decrease in Saireddypally.[7] The relatively high pre-Bt yields in Gudeppad and Saireddypally likely stem from both better information connectivity and better resources to purchase inputs including harvesting labor and insecticides. The relatively small yield advantage in these villages reflects the fact that the bollworms were better controlled than in Kalleda and Ravuru. With the shift to Bt, dispersion has also decreased: the coefficient of variation has dropped from 0.42 in 2003 to 0.32 in 2007.[8]

(b) *Pesticide use*

Although some studies by NGO's (e.g., Qayum & Sakkhari, 2005) and occasional figures in peer-reviewed literature (Morse *et al.*, 2007, Table 4) link Bt cotton to increased pesticide use, the strong pattern in peer-reviewed research is for insecticide use to drop with Bt cotton adoption (Bennett, Ismael, Kambhampati, & Morse, 2004; Bennett, Ismael, & Morse, 2005; Bennett *et al.*, 2006; Qaim, 2003; Qaim *et al.*, 2006). However selection bias is again a problem, as the higher levels of education and prosperity are known to affect insecticide use (Dasgupta, Meisner, & Huq, 2007; Qaim, 2003).[9] This panel comparison avoids selection bias. Both censuses elicited insecticide use from the previous season, and farmers were normally able to recall number of sprayings and the pesticides used the previous season with what we believed to be acceptable accuracy.[10] There are various measures of pesticide use (see Barnard, Daberkow, Padgitt, Smith, & Uri, 1998); this analysis uses the simple, robust, and common measure of number of sprays. Warangal farmers sometimes mix two insecticides into a single spraying, but this does not normally lead to application of double amount of spray.

Table 3 shows that overall mean sprayings dropped by 54.7% with adoption of Bt cotton. Inter-village differences are much smaller than with yields. The greatest reduction has been in Gudeppad, where insecticide use had been the heaviest. Standard deviations have also dropped sharply as well.

(c) *Changing insect ecology*

There has also been a marked change in the type of pest attacks during 2003–07. Major cotton pests include not only Lepidopterans such as the (misnamed) American bollworm (*Helicoverpa armigera*) but Hemipteran "sucking pests" that extract sap from leaves; important examples are the whitefly (*Bemisia tabaci*), cotton aphid (*Aphis gossypii*), mealybug (*Phenacoccus* sp., *Maconellicoccus* sp.), and mirid (*Creontiades* sp.). It is Lepidopterans that are targeted by proteins expressed by Bt *Cry* genes, and the question of impacts on non-Lepidopteran pests is complex (Lawo, Wackers, & Romeis, 2009; Showalter *et al.*, 2009). *Cry* genes have no established effect on sucking pests (Vennila *et al.*, 2004), but there is preliminary evidence that some Bt cotton hybrids are more susceptible to sucking pests (Kranthi, 2009).

Another possible impact on sucking pests is that Bt cotton leads to reduced applications of broad spectrum insecticides such as monocrotophos that affect both bollworms and sucking pests. (However insecticide use is also a *cause* of sucking pest problems; infestations with sucking pests such as whiteflies and aphids are a classic result of the pesticide treadmill.)

Bt cotton might also indirectly reduce sucking pest attacks; for instance, on experimental plots in northern China, reduced sprayings of Bt cotton spared predators of sucking pests and allowed for natural biological control of aphids (Wu & Guo, 2003). However, within a few years of the appearance of Bt cotton, field data showed that mirids had emerged as a major pest (Wang, Just, & Pinstrup-Andersen, 2008; Wu, Li, Feng, & Guo, 2002). Men, Ge, Edwards, and Yardim (2004) found that the additional sprays needed for sucking pests offset the reductions for bollworms, and Wang, Just, and Pinstrup-Andersen (2006, p. 625) reported that "secondary pests have completely eroded all benefits from Bt cotton cultivation." Lu *et al.* (2010) find the spread of Bt cotton in northern China to correlate with mirid outbreaks in multiple crops.

There is gathering concern that Bt's successes against Lepidopterans in India may be followed by similar onslaughts by sucking pests. Mirids are a rising menace in Karnataka (Udikeri *et al.*, 2008), and there are increasing claims of problems with other sucking pests (Economic Times, 2007; Financial Express, 2005). A recent study in Maharashtra (Lalitha *et al.*, 2009) found that 45% of sprays were for sucking pests (*vs.* 24% for bollworms) and in Gujarat 76% were for sucking pests (*vs.* only 7% for bollworms in this state where almost all farmers are growing Bt cotton).

The change in insect ecology in Warangal has been conspicuous. In 2003, my conversations with Warangal farmers were dominated by concern over Lepidopterans like American bollworm and *Spodoptera* cutworm; in contrast, conversations about the 2007 season were dominated by concern over aphids and by damage likely caused by aphids: "*mashi penu*" (leaf darkening) and "*mudatha*" (leaf shriveling). Some farmers were also complaining of mealybugs for the first time. Most fields that I saw in July and August showed heavy aphid infestations. Asked what pest (or pest damage) had prompted each of the sprayings recorded for 2007 ($n = 503$), farmers attributed 58% to aphids, *mashi penu* or *mudatha*; 19% to other sucking pests; and 23% to Lepidopterans. A full 99% of households sprayed for sucking pests at least once.

There had been a corresponding change in the pesticide market. Bollworm sprays with little or no action on sucking pests, which had been highly popular in 2002, such as indoxacarb (Avaunt), spinosad (Tracer), and chlorpyriphos (sold under many brand names), had become rare and discounted; organophosphates with broad-spectrum activity such as monocrotophos were still readily available. Nicotinoids like imidacloprid and acetamiprid, which are primarily effective against sucking pests, were everywhere and were selling at marked up prices. Acetamiprid alone is sold under at least six brand names (including Award, Scuba, Prime, Ennova, and Pride) and there is widespread confusion among farmers. In

Table 3. *Insecticide sprayings per farm on cotton in 2003 and 2007. All differences in means are significant at the .01 level*

	2003 excluding the 5 Bt planters			2007			% change
	Mean	sd	*n*	Mean	sd	*n*	
Gudeppad	11.9	4.4	145	5.1	1.4	59	−57.4
Kallada	6.9	3.9	37	4.0	2.0	16	−41.5
Ravuru	7.3	4.7	30	3.9	2.5	62	−46.7
Saireddypally	10.7	3.1	26	5.5	1.9	56	−49.0
Total	10.4	4.7	238	4.7	2.1	193	−54.7

an interesting change, the central display cases at input shops, which had usually been filled with high-demand cotton seeds a few years before, were now mostly filled with nicotinoid insecticides. [11]

4. THE FARM LEVEL: TECHNOLOGICAL CHANGE AND FARM MANAGEMENT

The major and rapid changes in yields, seeds, and pests in Warangal cotton farming underscore how dynamic and closely inter-related the many elements of agriculture are. It may also lead us to question how meaningful it really is to isolate individual elements of the system at one point in time. Any understanding of how these elements fit together into a system requires considering the social and institutional contexts noted by Smale *et al.* (2006), or shifting the gaze from the field to what we have termed the farm level. There turn out to be significant patterns that appear only by looking at long term trends in cotton cultivation. The 2003 season marked the end of a long period of downturn or stagnation in cotton yields at both the state and national levels. Figure 2 shows a nationwide pattern of steadily increasing cotton yields up to the mid-1990s, followed by a decline lasting through the 2002 season. It also shows that in Andhra Pradesh the changes in cotton yields were more pronounced, and a few years earlier than, the national trends.

Even without considering the factors driving cotton production down prior to 2003, we note that the shape of the trend provides an interesting context for the post-Bt years. Nationally, the spread of Bt cotton coincided not with an unprecedented surge in yields but with the correction of a six-year decline, leaving cotton yields more or less back on the path they had been on before the mid-1990s. In Andhra Pradesh, recovery from the disastrous production slump was actually underway four years before Bt cotton arrived (with a step backward in 2002 due to unusually low rainfall).

The question is what happened to cotton farming in the mid-1990s, and why it was particularly pronounced (and earlier) in Andhra Pradesh. These years, marked by what Vakulabharanam (2005) terms a cycle of "growth-inducing distress" and "distress-inducing growth," saw farm-level changes affecting management skill and agricultural technologies. The first key change was the movement of many farmers into (or deeper into) commodity cotton production following liberalization of policies beginning in the late 1980s and sharp increases in cotton prices in the early 1990s (Vakulabharanam, 2005). Nationally, the area planted to cotton during 1988–98 rose from 7.3 million to 9.3 million (Indian Ministry of Textiles, Indiastat). However, cotton prices reversed in the late 1990s, dropping by almost half from 1995 to 2001 (Vakulabharanam, 2005, Figure 3).

The second change was in the nature of the seed market that the growing population of cotton farmers faced—and helped shape in some unfortunate ways. Beginning in the 1990s, southern and central India became the only area in the world reliant on hybrid cotton seed, and in particular proprietary hybrid seed. Hybrid cotton is an Indian invention, developed at a public agricultural university in 1970. Released by public institutions during the 1980s, hybrid seeds gained a foothold in southern and central India (in Punjab, the late maturity of most hybrids made them less compatible with local cropping systems) (Lalitha *et al.*, 2009).

Proprietary hybrids differ from public hybrids in that they are produced and marketed by private seed firms, but they are usually created from parent lines from public institutions. They are often created relatively rapidly, and they may lead to identical crosses being marketed under multiple brand names (which also occurs with some seeds in the United States; see Ziegenhorn, 2000). Proprietary hybrids appeared in 1979, and in the 1990s began to gain momentum (Lalitha *et al.*, 2009); during 1996–2004 the area planted to proprietary hybrids climbed dramatically (Figure 3). As Murugkar, Ramaswami, and Shelar (2007) note, "In 1996 hybrid varieties accounted for about 55% of the total cotton area, but two-thirds of this was covered by public hybrids. By 2004, hybrids covered 6 million ha (two-thirds of the cotton area), of which 5 million ha were sown to proprietary hybrids."

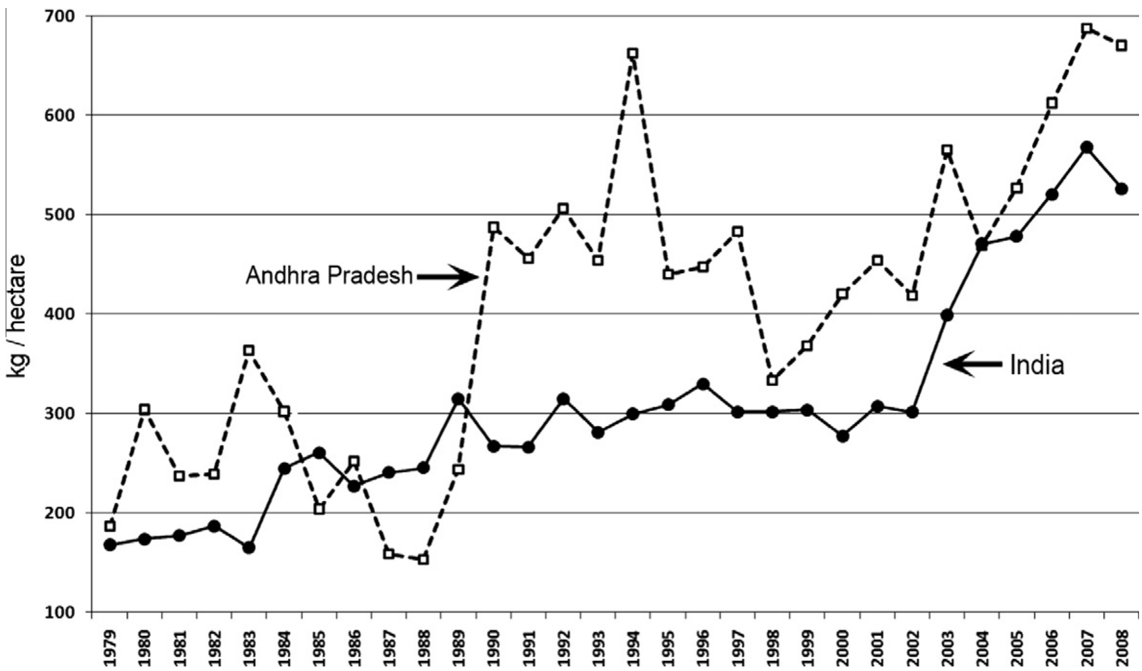

Figure 2. *India-wide and Andhra Pradesh trends in cotton yields. Source: International Cotton Advisory Board.*

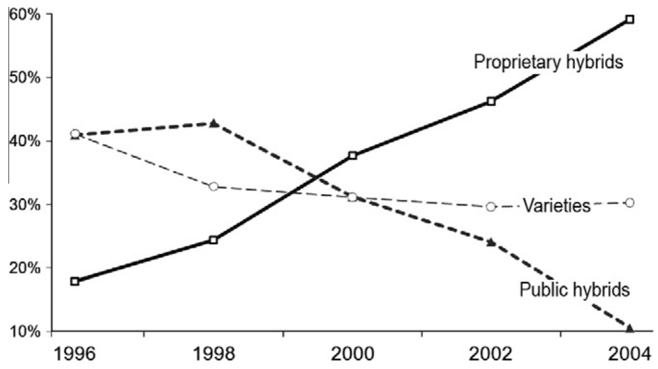

Figure 3. *India-wide patterns in seed types. Source: Murugkar et al. (2006).*

Andhra Pradesh began the 1998–2002 period with the country's highest reliance on proprietary hybrids and the rate climbed sharply from the mid-1990s to 2002 (Figure 4).

As farmers' practices were changing rapidly during this period, so was the seed market. Capitalizing on looser regulation of proprietary seeds than public hybrids and varieties,[12] seed companies and their seed brands were proliferating, as demonstrated by declines in market share of the top 5 firms (Murugkar *et al.*, 2007).

Therefore farmers in Andhra Pradesh (and to a lesser extent, in Maharashtra and Gujarat) were increasingly relying on seeds purchased anew each season from a proliferating seed market. Hybrids, as Fitzgerald (among others) has pointed out, are an innovation with real consequences for farm management: they "effectively locked farmers out from an understanding of their own operations without the aid of experts… where open-pollinates were transparent, hybrids were opaque" (Fitzgerald, 1993, p. 342). Clearly, few Indian cotton farmers had access to "experts," and external management instruction is of dubious value for these smallholders anyway (Stone, 2011). We should therefore expect these changes to have increased farmer vulnerability to agroecological problems that challenged management skill.

Such a problem is precisely what arrived in the form of the previously mentioned "pesticide treadmill." The proprietary hybrids spreading in these states during this period were virtually all intra-hirsutum crosses,[13] which lacked resistance to Asian pest species (Kulkarni, Khadi, Maralappanavar, Deshapande, & Narayanan, 2009) and required liberal doses of insecticide. Warangal farmers were not strangers to pesticides by the 1990s, but never before had they relied so heavily on a crop with so many pests, so little natural resistance, and in such apparent need of sprays. There was virtually no indigenous knowledge of the organophosphate and synthetic pyrethroid sprays on offer at the ubiquitous input shops, and overuse and misuse of insecticides spread alongside the hirsutum hybrids. During the 1990s, pesticide use was estimated to be growing at 20% per year, with the great majority going to cotton (Reddy & Rao, 1998); Andhra Pradesh was near the top of the list in *per capita* pesticide use. With the rise of heavy insecticide use came the inevitable insect resistance. Resistance in *Helicoverpa* had been reported in Andhra Pradesh in 1987 (McCaffery, King, Walker, & El-Nayir, 1989) and other bollworms soon after (Armes, Wightman, Jadhav, & Ranga Rao, 1999); by the late 1990s, most bollworms and some sucking pests showed strong resistance to pesticides (Kranthi, Jadhav, Wanjari, Ali, & Russell, 2001; Kranthi *et al.*, 2002).

In the 1997 season, when Warangal made headlines with farmer suicides widely attributed to bollworms (e.g., Times of India, 1999), several factors intersected. There had been considerable recent expansion of area planted to cotton, a steep decline in cotton prices, and rising resistance to insecticides. In addition, Warangal rainfall patterns encouraged unusually severe attacks by *Spodoptera* cutworms (Reddy & Rao, 1998). At the field level, the result was that Warangal farmers responded by increasingly spraying decreasingly effective pesticides, ending the season with enormous debts and a meager crop (Reddy & Rao, 1998). However, from a farm-level perspective there appears to have been a general management failure of which the bollworm damage was merely a symptom.

Such management failure has been theorized as "agricultural deskilling" which may be synopsized as follows (Stone, 2007a):

- Farm management skill (in nonindustrial contexts) is based not on static "indigenous technical knowledge" but on the ability to "perform" (Richards, 1989, 1993). It is not static, but rather an ability that must be continually updated and refined, especially when there are changes in market conditions, input technologies, pests and diseases, government policies, and even new ideas. This ongoing process of learning to perform with given technologies under changing conditions is *agricultural skilling*.
- How skilling actually occurs is complex.[14] Drawing on work by behavioral ecologists (Boyd & Richerson, 1985; Henrich, 2001; McElreath, 2004), it is helpful to distinguish between environmental learning, which is based on evaluations of payoffs from various practices, and social learning, in which adoption decisions are based on imitation.
- Social learning is an indispensable part of human adaptation but it has intrinsic biases. One is *prestige bias*, in which a farmer chooses which farmer to emulate on the basis of prestige, regardless of the other farmer's actual success with the trait being copied. Another is *conformist bias*, in which a farmer adopts a practice when (and because) it has been adopted by many others. Reliance on "pure social learning" should be high when environmental learning is costly and/or inaccurate (McElreath, 2004; Richerson & Boyd, 2005, pp 13, 14). Social learning may lead to the spread of maladaptive beliefs, especially when the environment changes very

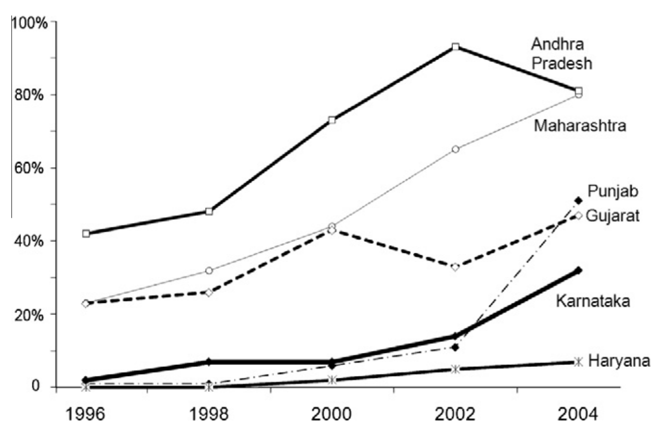

Figure 4. *State-specific trends in types of cotton seeds; the y-axis indicates the area planted to proprietary hybrids. Source: Murugkar et al. (2006).*

rapidly (Richerson & Boyd, 2005, p. 118). The phenomenon is also recognized in economics, where it is known as an information cascade (Banerjee, 1992; Bikhchandani, Hirshleifer, & Welch, 1992).

- Failure of the ongoing process of learning to perform under changing conditions is *agricultural deskilling*, a condition differing in some key respects from the better-known industrial deskilling (Braverman, 1974).[15]

Specific causes of deskilling in Warangal cotton farming were identified as inconsistency, unrecognizability, and an excessively rapid rate of change in cotton seed (Stone, 2007a). Patterns of seed choice gave conspicuous evidence for deskilling. Although choice of seed is one of the most serious decisions the farmer makes each year, farmers in all study villages relied heavily on "pure social learning," producing a surprising pattern of highly localized seed fads, driven not by local agroecology but by marketing and happenstance. In counterpoint to the classic model of farmers adopting new seed only after careful evaluation of test plots, Warangal farmers showed a keen desire for new and untested seeds, which encouraged the churning of the seed market with new releases (including releasing seeds under multiple names). In 2005, most local fads converged on the same seed, causing a district-wide run on a new Bt seed named RCH2-Bt: in nine sample villages, 63% of the cotton-buying households bought at least one box of this seed. Seed fads lacked agroecological rationales, and were sparked by marketing, influential farmers, and vendors (Stone, 2007a, pp. 78–82). It is interesting that Chinese cotton growing villages have also recently been found to have local favorite seeds that change too quickly to be the result of experimentation (Huang, Chen, Mi, Hu, & Osir, 2009; Tripp, 2009a, p. 233).[16]

This provides an historical context to the farmers' predicament as Bt seeds came into Warangal. The seed fads reflecting agricultural deskilling would have been the product of a decade of sharply rising area planted to proprietary hybrid cotton seeds, grown with heavy use of pesticides, against a backdrop of unstable cotton prices and insect ecology. There is no doubt that at the field level, the result was Warangal farmers having a serious bollworm problem in the early 2000's, or that Bt cotton has helped ameliorate yields and insecticide use. However from a historically grounded farm-level perspective, the role of Bt cotton is less clear. The real problem that had gripped the Warangal cotton farm was a fraught relationship with rapidly changing, largely unrecognizable technology, which had destabilized the crucial process of agricultural skilling. This clearly leads to the question of what, if any, effect the new technology has had on this underlying farm-level problem.

5. BT COTTON AND DESKILLING

Agricultural deskilling preceded the arrival of Bt cotton, but there were reasons to anticipate that the spread of Bt cotton would exacerbate the problem. One reason was that the new cotton arrived with an unprecedented wave of wildly contradictory advertising, campaigning, and lobbying aimed at farmers, with false information being spread by its backers and detractors alike. The most famous misinformation from anti-GMO activists was that Bt cotton contained "Terminator" gene use restriction technology which rendered seeds sterile (Herring, 2006). The claim was not only false (the technology was experimental and never commercialized) but ironic: most of the farmers were already planting hybrid seeds that were partly responsible for their predicament. Meanwhile, marketers spread the word that Bt cotton eliminated the need for pesticides, which was likewise false.[17]

A second cause for concern regarding deskilling was that Bt cotton brought a new category of accelerated technological change: not only a flood of new seeds containing the original Bt gene, but then a procession of new Bt genes and constructs. During 2002–06, all Bt cotton in India contained the same genetic construct, based on the Cry1Ac gene. Even with one construct, expression varies with the hybrid into which it has been bred, the age of the plant, and various environmental factors (Dong & Li, 2007; Kranthi *et al.*, 2005). Since 2006, three new constructs (based on different genes, versions of genes or combinations of genes) have been approved, and by 2008 there were 281 separate branded hybrids incorporating the four different Bt technologies (IGMORIS, 2008). The variability in performance of these new constructs was not known in the scientific literature, let alone by Warangal farmers or vendors. None of the Warangal vendors or farmers I interviewed in 2008 understood that there were now four versions of Bt to choose from, or how they differed. What most farmers had heard was that there was now the option of "double Bt." The pace of change in transgenic technologies will only quicken; by 2009 two new Bt events had been approved, and the total number of approved Bt seeds was up to 284 (Foreign Agricultural Service, 2009). This situation is celebrated by biotechnology companies (e.g., Henderson, 2005) but it is certain to exacerbate the skilling gap.

It is difficult to isolate the impact of the spread of Bt cotton on farm management, but a recent update shows a strengthening of the pattern of district-wide fads or cascades, in seed choice. The 2008 survey (described above) found that the RCH2-Bt fad ended abruptly, to be replaced by an even wider fad for Mallika-Bt seed: among farmers buying cotton seed in 2008, at least one box was Mallika-Bt a remarkable 87.6% of the time. As with RCH2-Bt, this fad was driven overwhelmingly by emulation: when asked why they selected Mallika-Bt, most farmers reported that it was what others were buying, or that the "buzz" on this seed was positive ("*talk manchiga vachindi*"). Neither vendors nor farmers could explain the demise of RCH2-Bt. Soon after this, Mallika sales too began to drop. In summer 2010, a small randomized survey was conducted on 45 Kalleda and Ravuru farmers who reported 182 seed purchases in 2009. The percentage of cotton-buying households with at least one box of Mallika was 49%, and Brahma had emerged as the new favorite in Kalleda.

The ephemeral nature of local seed favorites is only visible in a multi-year study; a shorter study would simply conclude that local favorites were adapted to local conditions (e.g., Ramaswami, Murugkar, & Shelar, 2009). Sadashivappa and Qaim (2009, p. 175) do not chart individual seed brands, but they do present multi-year data showing farmers going back and forth between Bt and conventional seed. Their claim that this reflects farmers learning and adjusting would seem to be questionable if farmers are careening from seed to seed as in the Warangal case.

6. DISCUSSION

The plight of Warangal cotton farmers has come under the microscope because of the centrality of this controversial district in India and of India in global GMO debates. Thus field-level agronomic specifics in this one corner of Asia have taken on an outsized significance in a global controversy that is animated by much larger issues. We have, on one hand, a global constituency that contests the spread of agricultural biotechnology on mostly political-economic grounds including effects on intellectual property regimes, funding priorities, and other articulations between the industrialized and developing worlds. On the other hand, we can recognize nexuses of corporate biotechnology, academic science, and state trade interests with a keen interest in developing-world success stories. There is much at stake, and the claim that transgenic technologies are "just another tool for the farmer" is true only in the studiously myopic sense that the textile mills in England's Industrial Revolution were "just another tool" for making cloth. But the debate has followed a trajectory with enormous emphasis on empirical field-level measurements, and given the pervasive vested interests and strong antipathies, claims of resounding field-level "success" or "failure" have found ready audiences.

One result has been the persistence of a legend of failure and rejection of Bt cotton (Herring, 2008) with lurid claims of livestock death and farmer suicide. On the other hand are writers pronouncing Bt cotton a major success based on literature that is actually inconclusive—dominated by short-term studies, hampered by biases, and generally oblivious to changes in the ecology of non-target pests. In this situation, longitudinal, multi-village, multi-ethnic, probabilistically selected, ethnographically grounded studies that avoid bias are helpful. This is one such study, and it shows that as Bt cotton replaced conventional cotton in Warangal, yields rose 18%, with the greatest increases in the poorest villages, while insecticide sprayings dropped by 54.7%. Predation by non-targeted pests has also surged, making it unclear how long these gains will be sustained, but at the field level the results are generally positive. However from the level of the farm, the picture is neither as simple nor as positive, because it is doubtful that bollworms are really the "devastating problem" (Herring, 2008) that confronts farmers. The bollworm attacks that preceded the arrival of Bt cotton did not result from mere ecological happenstance, but from a history of increasing devotion to cotton, adoption of pest-prone seeds and pesticides, spread of proprietary hybrids in a rapidly changing and poorly regulated market. These trends affect farm management, and they help explain the situation in Warangal District, in which rapidly changing and unrecognizable agricultural technology led to agricultural deskilling.

At the field level, the advent of proprietary pesticide-intensive hybrids may seem good for the cotton farmer, at least as reflected by adoption rates; so too the successive waves of new pesticides and new seed brands that were embraced by farmers. With bollworm an increasingly intractable problem, the arrival of Bt cotton has been hailed as good news, the new Bt cottons may soon be hailed as better news, and when sucking pests become unmanageable, a next generation of GM seed may be the best news yet. However, at the farm level this news is not particularly good at all. If these field problems are in fact symptoms of a severe and systemic disorder in the skilling process, precipitated by unrecognizability and accelerated technological change, then the latest round of technology may prove to alleviate symptoms at the expense of exacerbating the underlying cause.

NOTES

1. Readers interested in the literature of Bt cotton in developing countries are referred to these two references and to Tripp (2009b), Herdt (2006), Raney (2006), and Showalter, Heuberger, Tabashnik, and Carrière (2009).

2. Gujarat has contributed the most to India's rise in cotton yields since introduction of Bt, and its experience was unique because of the pivotal role played by seeds with pirated Bt technology that performed better than the legal seeds (Herring, 2007; Stone, 2007b).

3. The Indian cotton season straddles two calendar years, as it is usually planted in May-July while harvesting may last into February. For ease of reference, I refer to cotton seasons by the year of planting.

4. This problem may be mitigated by attempting to statistically adjust for differences in sample groups (Crost *et al.*, 2007), but the results remain much less revealing than an unbiased comparison.

5. At the launch of one study, the sponsors openly challenged farmers who reported good results with Bt cotton (Stone, 2005).

6. The 2004 census was conducted in collaboration with agricultural economist A. Sudarshan Reddy of the Centre for Environmental Studies, Hanamkonda. The census included household demographic and economic information along with data on each crop grown, how seeds were chosen and where they were obtained, what inputs were used, and what was harvested. Interviewing was done by myself, Reddy, and well trained Warangal indigenes, most of whom were college graduates in agricultural economics. All interviewers (except myself) and respondents were native Telugu speakers and interviews were conducted in Telugu. The 2008 census was conducted by myself and one assistant, also a native Telugu-speaker native to Warangal.

7. Sadashivappa and Qaim (2009) present panel data spanning 2002-2006 but it is difficult to compare to because both Bt and conventional cotton were being cultivated.

8. Differences in rainfall during 2003–07 would have accounted for very little of the change in cotton yields. According to the Andhra Pradesh Directorate of Economics and Statistics, Warangal received 991 mm. of precipitation in the 2003–04 season and 1108 mm in 2007–08 (the 15-year average was 975 mm). An earlier census found that 65% of households had access to a source of irrigation which buffered fluctuations in rainfall.

9. On the other hand, some Chinese studies show Bt planters do not decrease their spraying as much as they could (Pemsl, Waibel, & Gutierrez, 2005; Yang, Iles, Yan, & Jolliffe, 2005).

10. When farmers responded with ranges ("3–4 sprays") we used midpoints (3.5).

11. These inputs may have different implications for credit. For instance, Kambhampati, Morse, Bennett, and Ismael (2005) found that in Gujarat, input vendors sought to move away from pesticide sales (which were normally done on credit), preferring Bt cotton sales (cash up front).

12. The Seed Acts of 1966 and 1983 establish a system of variety release, seed certification and seed testing. "Varieties are released after evaluation at multi-location trials for a minimum of three years. Varieties approved are 'notified' which is a prerequisite for certification. While all public sector varieties go through this process, it is not mandatory for private varieties… However, uncertified seeds are required to be truthfully labeled listing quality attributes on the label" (Murugkar, Ramaswami, & Shelar, 2006).

13. There are two species of cotton indigenous to south Asia, but *Gossypium hirsutum* is a New World species, favored for its productivity and fiber qualities. A tetraploid plant, it is difficult to cross with the diploid Asian species.

14. In India the recent trend has been to fetishize the role of information/communication technology in farm management in ways that appear to benefit farmers less than input providers and policy makers (Stone, 2011).

15. I am also defining the term somewhat differently from Fitzgerald, for whom it is essentially Braverman's (1974) concept but "shorn of its political charge" (1993, p. 324).

16. One recent study of cotton farmers in Gujarat and Maharashtra (Lalitha *et al.*, 2009) appears to show a higher reliance on small-scale experimental plots, but the presentation of data makes comparisons with Stone's data difficult. These findings also would seem to indicate that farmers are planting many very small plots, but seed is only marketed in packages large enough to seed one or two acres; this would be an unusual practice, and it was not investigated (Ramaswamy, pers. comm., 2010).

17. A Monsanto marketing director was quoted as claiming that Bt cotton would have prevented the Warangal suicides (Vidal, 1999), although the cotton was ineffective against the Spodoptera worms that plagued farmers in 1997–98 (Reddy & Rao, 1998). Not until 2008 was a Bt cotton released containing a construct claimed to be effective against Spodoptera.

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