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Hybrid Realities: making a new Green Revolution for rice in south India

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ABSTRACT

Indian policy makers and agronomists often argue that hybrid rice varieties can help raise aggregate yields to address food security and improve rural incomes. Indian farmers, however, have proved hesitant to embrace this technology. To explain the disjuncture, this paper analyses the case of a publicly developed and promoted hybrid variety in southern Karnataka. It highlights how, within the context of growing social polarisation and an increasingly water-scarce agrarian environment, many smallholders found the hybrid unsuited to cultivation strategies that increasingly sought to minimise risk. The paper therein further illustrates the limits of technological solutions to contemporary agrarian distress.

KEYWORDS

Hybrid rice; new Green Revolution; political agronomy; political ecology; India

The year 2016 marked a half-century since the release of IR-8, the semi-dwarf rice variety that formed a fulcrum of the Green Revolution in Asia. For the International Rice Research Institute (IRRI) – the leading international centre for agronomic research on rice – the anniversary was cause for celebratory retrospectives. Couched in an awkward mix of scientific lexicon and religious jargon, the publicity surrounding IR-8 rehearsed a now familiar narrative of heroic scientists conjuring a miraculous agronomic breakthrough that saved much of Asia – and particularly India – from the ravages of famine.[1] While such interpretations have been questioned within recent literature on the Green Revolution (e.g. Cullather 2010; Kumar 2016), IRRI nonetheless used the anniversary to steadfastly reproduce the idea that the past, present and future of global food production lies in the hands of dedicated agronomists. By developing new breakthroughs in breeding techniques and genetic manipulation, the latter are charged with the task of keeping Malthus' ghost sealed beneath six feet of highly productive earth.

Within India, this search for a 'new Green Revolution' in rice production has repeatedly focused upon the potential of hybrid varieties to propel an advance in yield gains (Viraktamath 2011; Spielman, Kolady, and Ward 2013). Owing to the heterosis effect – in which the first generation offspring of two distinct parent lines typically demonstrate superior growth and productivity – rice hybrids may provide a means to raise yields above those of the high-yield varieties (HYVs) that characterised the original Green Revolution

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[1]See http://irri.org/ir8 (accessed Feb 25, 2018).

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period. Comparison is often made to China, where hybrids now constitute over half of sown paddy and yields are reported to be around double the Indian average.[2] On this basis, the Indian government has regularly placed the promotion of hybrids at the heart of its national agricultural development strategy. Notwithstanding significant promotion through public extension systems, however, the uptake of hybrid rice seed by Indian farmers has been slow, patchy and prone to setbacks. Only between six and eight percent of the national sown area of rice was under hybrid varieties in 2015, which contrasts starkly with the official target of 25 percent (Janaiah and Debdutt 2017).

The failure of successive governments to realise targets for hybrid adoption has caused considerable consternation in the agronomic community because a projected leap forward in yields is repeatedly tied to future food security in conditions of population growth and mounting environmental constraints (Mohanty and Yamano 2017). There remains, however, significant disagreement on why Indian farmers have proved reluctant to embrace this technology, with many accounts claiming that the development of hybrid varieties better adapted to local conditions and tastes is key to promoting increased adoption among smallholders (Spielman, Kolady, and Ward 2013; Sivagnanam 2014). To open an empirical window on this question, this paper traces the genesis and uneven diffusion of one such locally adapted variety of hybrid rice – KRH-4 – produced by researchers at the agricultural university and zonal research station in Mandya, Karnataka. In technical terms, KRH-4 represents a success story. Measured in national testing, it manifests strong yield potential, disease resistance and other key indicators of performance that are argued to make it well suited to south Indian conditions. On this basis, KRH-4 exemplifies the kind of locally adapted hybrid that researchers and policymakers hope can spearhead stronger adoption trends among the smallholder population as a means to raise both productivity and farmer incomes. Notwithstanding such expectations, however, field research showed that KRH-4 held only a minimal presence in farmer fields five years after its local release despite concentrated institutional promotion.

To explain this contradiction between a technology purportedly designed to meet smallholder needs and the lack of adoption by target farmers, the paper adopts a political ecology perspective that elucidates two intertwined facets of technology transfer. First, the paper analyses the complex knowledge politics and institutional drivers surrounding the genesis of KRH-4 within a public system that operates in an increasingly commercialised research environment. This perspective is significant because much literature on technology transfer neglects to analyse how and why particular innovations are designed, championed and promoted. Based on fieldwork conducted with farmers, extension officers, agricultural scientists and other actors in the rice processing chain, I trace out the pressures upon researchers to deliver an agronomic 'success story' that could subsequently be commercialised through tender to the private sector. To do so, researchers and extension agents had to disseminate their new variety within an agrarian environment in which competing private sector actors and agrarian social movements offered distinct alternatives to public sector seeds. These complex institutional dynamics shaped how subsidised extension networks sourced the hybrid into concentrated yet fragile pockets of

[2]IRRI's data for 2014 puts average Indian yields at 3.62 tonnes per hectare and Chinese yields at 6.75. These differentials are reflective primarily of the more widespread availability of irrigation in China. Historically, the greater use of hybrids in the latter was driven by the authoritarian nature of governmental policy that mandated hybrid use on food security grounds in the 1980s (Janaiah 2002).

adoption that were geared as showcases to external audiences as much as local farming populations.

Second, in contrasting the institutional projection of success with limited field-level presence, I analyse why hybrids in this region are not being adopted despite claims to their agronomic superiority. To do so, I situate the dynamics of technology transfer within the political ecology of an agrarian environment characterised by tightening livelihood constraints, social polarisation and increased climatic variability. Placed within this context, hybrid seed appears to be a technology appropriate to a minority of relatively affluent farmers that possess the requisite socio-economic resources and networks to effectively manage the technical demands, agroecological uncertainties and financial costs involved. Paradoxically, one further group encountered using hybrid seeds was a small section of marginal landless farmers. The latter felt compelled by the weight of indebtedness to pursue high-risk, high-reward cultivation strategies on rented land simply to make ends meet. For the bulk of smallholders, however, the potential yield gains are offset by risks implied in increased input costs, more demanding cultivation practices, uncertain product markets and the increasing incidence of drought. These fundamental tensions at the heart of smallholder agriculture cannot be resolved through recourse to transformative technologies alone. Indeed, the latter may well exacerbate them.

The political ecology of hybrid rice

The literature on agricultural technology transfer has charted a wide range of technical, social, institutional or agroecological impediments that affect the diffusion of a new technology and its accompanying knowledge system (Röling 1990; Sunding and Zilberman 2001). Contemporary political ecology provides two further entry points. First, drawing upon science and technology studies (STS) and discourse analysis, studies within the rubric of 'political agronomy' analyse how changing institutional and technological logics configure agronomic knowledge production, including how research agendas and priorities are constructed, how their legitimacy is determined, and how claims to success are created and propagated within the field (Sumberg, Thompson, and Woodhouse 2012; Sumberg 2017). By tracing how these institutional contexts of funding, collaboration, partnerships and stakeholder engagement shape the goals, processes and results of research, political agronomists problematise the interactions between agricultural governance and development policy at various scales ranging from extension initiatives at the local level through to agenda setting within international institutions (Whitfield 2015; Rao and Huggins 2017). As I illustrate below, these institutional dynamics are vital for understanding contemporary technology transfer because, in the context of mounting pressures upon public researchers to translate agricultural innovations into commercially viable products, they strongly shape the mechanisms through which new hybrid rice seeds are designed, legitimated and diffused to local populations and other stakeholders.

Second, the dynamics of technology transfer must be set within a regional political ecology of agrarian change that shapes who performs agriculture, under what circumstances, and with what livelihood implications. To understand why the promotion of this hybrid rice variety struggled to catalyse widespread adoption in south India requires an analysis attuned to the dynamics of accumulation and marginalisation that accompany

structural and environmental change in rural regions. In the Indian context, four broad processes can be identified as central drivers of agrarian change over the past three decades: (1) the numerical expansion of smallholder agriculture, with a significant increase in small and marginal holdings that compels households to craft complex livelihood strategies inside and outside of agriculture (Harriss-White 2008; Pattenden 2016); (2) a shift towards the commercialisation of agriculture, with increased outlays of capital on inputs and greater dependence on unstable market prices (Reddy and Mishra 2009; Kammardi et al. 2017; Aga 2018); (3) an individualisation of risks owing to declining state support, the breakdown of former patronage relationships and the undermining of common property resources (Jodha, Singh, and Bantilan 2012; Vasavi 2012; Ramprasad 2018); and (4) mounting tensions within the ecological basis for agriculture owing to the long term impacts of intensive farming manifested in trends such as soil degradation and groundwater depletion alongside climatic change (Taylor 2013). As I detail below, while these four trends provide essential context for understanding technology transfer successes and failures, they do not manifest themselves uniformly across an agrarian environment. Rather, they emerge in the context of hierarchical social relationships structured around divisions of class, caste and gender that unevenly apportion the gains and risks associated with agricultural production in contemporary India.

Drawing these two strands together provides a strong analytical basis on which to examine the promotion of hybrid rice in south India. Field research was undertaken in Mandya district of Karnataka in the summer of 2017 to trace how networks of researchers, extension officers and farmers shaped agricultural practices and technology transfer, with both intended and unintended effects. To this end, 45 semi-structured interviews were conducted with rice cultivators, millers, input dealers, two sets of extension agents, and scientists at the local agricultural university working on rice breeding, water management and soil health. Collectively, these interviews provided key insights into the institutional networks through which KRH-4 was designed, tested, trialled and commercialised. At a farmer level, the research was founded upon visits to three villages that were focal points for the institutional demonstration and diffusion of KRH-4 during its local release in 2012. Interviews focused on farmers who had either cultivated KRH-4 or known of its usage over the previous five years. Farmers were asked about how they choose between seed types; their sources of knowledge and instruction regarding suitable varieties and cultivation techniques; their previous and/or present experience with hybrids; their experience using KRH-4 (where applicable); their selection of cultivation methods and inputs; and their means of access to land, water, labour, insurance and credit. These discussions were complemented by interviews with researchers and extension officers in the agricultural university and the public extension system about KRH-4 specifically alongside other extension strategies for intensifying rice production. Finally, a selection of agents in the rice value chain was also interviewed, including input dealers, traders and millers to provide contextual information about markets for KRH-4 and other varieties in the region.

High hopes for hybrids

The expectations vested in hybrids as a next wave of technological innovation in Indian rice research rests on their potential to raise the yield ceiling beyond standard varieties

owing to what is termed the heterosis effect (Janaiah, Ahmed, and Viraktamath 1993). Heterosis represents a phenomenon in which the first generation of a hybrid plant demonstrates 'hybrid vigour' in the form of more rapid growth with expected higher fertility and overall biomass (Duvick 1999). Although the heterosis effect is only sustained for a single generation, in rice it is argued to raise the yield ceiling by as much as a thirty percent over non-heterosis plants. Given the slowing rate of yield increases achieved through conventional breeding methods, it is precisely the potential of hybrids to power a leap forward in rice productivity that excites both agronomists and policymakers alike (Singh et al. 2015).

First systematically explored by US agronomists working on maize in the early decades of the twentieth century, the development of hybrid seeds to capture the heterosis effect is now a longstanding practice for agronomic researchers across a number of crop types (Kingsbury 2009). In contrast to maize, however, the production of successful rice hybrids is a more technologically sophisticated process owing to the biological constraints posed by rice being a self-pollinating plant. Researchers must first carefully create two parental lines with desired qualities through standard breeding methods. Unique to rice, however, they must then render one of the parent lines male-sterile to rule out self-pollination. This exacting technique often involves the use of a third 'maintainer' line and requires great care to ensure that the desired genetics traits are retained in the resulting sterile line. Once the latter have been developed, the desired hybrid seed must then be produced through a complex breeding process that requires the staggered cultivation of the two parental varieties in carefully ordered lines to ensure simultaneous flowering. At the beginning of this short reproductive phase – flowering typically lasts less than seven days – the two plants are physically brushed together to encourage transfer of pollen from the non-sterile male parent into the female receptors of the other line.

Given that small errors at any point of hybrid production can lead to poor quality seed, these techniques require a facilitating institutional environment for both research and seed production. Initially, research on hybrid seeds was viewed as a public good owing to the potential benefits it might provide for national food security and the national government has consistently directed funding into public sector hybrid research since the early 1980s. Private sector interests, however, soon recognised the commercial potential of hybrid lines. First and foremost, the failure of the heterosis effect to sustain from one generation to the next precludes farmers from saving seeds for replanting. They must instead purchase new hybrid seeds on an annual basis. Growing hybrid usage therefore creates the potential for an expansion of the seed market with a concurrent demand for related chemical inputs such as fertilisers designed specifically for hybrid use. Put simply, the promotion of hybrid seeds represents an important accumulation strategy for agri-tech companies (see Berlan and Lewontin 1986; Kloppenburg 2004). At the same time, the current intellectual property rights regime in India gives strong protection to producers, providing an institutional context in which companies feel investments in hybrids are relatively secure (Chaturvedi and Srinivas 2017). Emboldened by this institutional framework, corporate involvement in hybrid research in India has been substantial, including a public-private partnership with the Maharashtra Hybrid Corporation (Mahyco) across the 1990s to facilitate incipient Indian research, and major investments in hybrid research and production since the 2000s.

As a result, private sector investment currently far outpaces public sector research, and private sector seeds dominate the Indian market, often backed by extensive advertising campaigns. Bayer, Syngenta and Mahyco currently have the most substantial presence and new international and domestic companies are producing hybrid varieties despite the slower than expected growth of the market among farmers. In response, a number of agrarian social movements have labelled hybrids as an emblematic expression of the corporatisation of the food system that encapsulates the deteriorating control of farmers over the genetic basis of their livelihoods (Living Farms 2011). Organised political resistance to hybrids, however, has not appeared necessary to stymie their spread. Despite the public and private emphasis placed on the potential of hybrid rice seed to raise yield ceilings, a number of problems have been associated with their use in India. These include technical issues related to inferior grain quality, inadequate disease or insect resistance, poor taste or texture and inconsistent yields (Janaiah 2002; Spielman, Kolady, and Ward 2013; Singh et al. 2015). In part, such problems occur because hybridising two south Asian *indica* varieties produces only a limited heterosis effect. A greater heterosis effect can be created from crossing an *indica* varieties with East Asian *japonica* varieties, yet the latter are less well adapted to south Asian conditions and their shorter grains do not accord well with local consumption tastes (Brar, Singh, and Khush 2017). This means that *japonica* varieties must first be extensively altered through standard breeding methods in order to create a suitable parent strain for Indian conditions that is less susceptible to disease and pests.

Outside of such technical constraints, the usage of hybrids faces social barriers in terms of the high cost of seed and a shift in cultivation practices associated with their use (Nirmala, Vasudev, and Suhasini 2013; Prakash et al. 2017). The latter includes different planting and nutrient regimes. On the one hand, hybrids are typically planted with greater spacing through the careful transplantation of a single seedling per hill. This requires a shift in transplanting practices among what is typically a low-paid and highly feminised workforce that – landowners often argue – requires careful supervision any time standard practice is altered. On the other, as K.R Krishna notes, the introduction of hybrids requires relatively higher and more precise doses of fertiliser to support both grain and straw production. Given the rapid growth of hybrids, nutrient turnover is more extensive during cultivation, with complex impacts on soil biota and high risk of negative impacts through inexact fertiliser dosage. For Krishna, the extension of hybrid cultivation signals a new kind of nutrient cycling regime that requires 'close attention to the potential for rampant loss of nutrients via volatization, leaching or erosion and contamination of ground water' (Krishna 2010, 163; see also Ali 2015: for an account of nutrient management with the KRH-4 hybrid).

Owing to these constraints, the spread of hybrid seed among smallholders during the 1990s and 2000s remained modest in India. Notwithstanding this trend, the Indian government has maintained that hybrid development and promotion is a key priority for agricultural research and has created new criteria for the development of hybrid lines. This follows what the FAO identified as a 'pan-Asian agenda for sustainable hybrid rice development', including (1) the development of new hybrids with a grain quality comparable to standard varieties, with wider adaptability across agroecosystems; (2) a further increase in yield potential; and (3) a reduction in retail seed price and a strategy to improve adoption among smallholder farmers; and (4) an improved extension focus on appropriate

cultivation and management strategies (FAO 2014). In many respects, the hybrid rice KRH-4 produced at the zonal research station in Mandya represents an agricultural research innovation that explicitly sought to meet these goals. As such, it provides a useful empirical window to throw light onto the dynamics of hybrid rice promotion in southern India.

The genesis of an agricultural innovation

As you enter the city of Mandya in southern Karnataka, a sign proudly announces the district as the 'sugarcane capital of India'. Yet paddy is typically cultivated on almost a third of all hectares sown, making it first among the big three crops (rice, ragi and sugarcane) that predominate in the region. This concentrated presence of a water intensive crop emerged historically with the development of a large-scale canal irrigation system during the late colonial period. Following the completion of the Krishnaraja Sagar dam across the Cauvery River in 1931, an extensive network of channels was constructed to carry water inland from the reservoir that borders the southern limit of the district. The expansion of irrigation provided the hydrological basis on which to transform the district from a semi-arid region characterised by the subsistence oriented production of millets and lentils into one focused closely on the key colonial crops of rice and sugarcane. Subsequently, the canal system was extended through an increasingly intricate series of channels that moved water across the district. In some areas localised tank systems add to water availability while, over the past three decades, there has been an increasing use of groundwater accessed through privately owned borewells. Finally, in those areas that border the Cauvery, Hemavathi or Shimsha rivers, lift irrigation pumps water directly onto neighbouring fields.

The expansion of irrigation under colonial auspices went hand in hand with governmental strategies to promote agricultural modernisation. Completion of the command irrigation system in 1931 was coordinated with the opening of an agricultural research station named after the Vishweshwaraiah Canal and known locally as VC Farm. With over 250 hectares of attached land, this research station was intended to stimulate regional crop production through applied agronomic research. Following independence in 1947, it was duly integrated into the national agricultural university system as a Zonal Agricultural Research Station (ZARS) of the University of Agricultural Sciences, Bangalore. In terms of rice production, VC Farm initially followed the standard practice of identifying, studying, improving and distributing locally adapted landraces as a means to raise regional productivity (Swarna, Sattar, and Sharma 2010). In the late 1960s, however, it became a regional focal point for the diffusion of HYVs created in both national and international research stations. While IR-8 – heralded as the showpiece of the Asian Green Revolution in rice – was trialled at VC Farm, the most important initial Green Revolution variety for southern India was called Jaya. Released in 1968 this variety was better adapted to local conditions and tastes and became the signature HYV for the region. As noted below, the variety is still extensively cultivated in Mandya district along with more recently developed HYVs such as Thanu, IR-64, MTU-1001, Jyothi, BR-2655, MTU-1010, and BPT-5204.

Research on hybrid rice at VC Farm began in 1981, when interest in the potential of hybrids was stimulated in light of the Chinese experience. Initial imports of Chinese varieties, however, displayed unsuitability to local conditions owing to low tolerance to

local pests and diseases. As a result, developing locally adapted hybrid varieties through the laborious development of suitable parent lines became the priority within Indian rice research (Swarna, Sattar, and Sharma 2010). A national network was formed and VC Farm became one of three hybrid research centres for southern India (Viraktamath 2011). Stimulated by a national level programme to support the development hybrid varieties led by the Indian Council of Agricultural Research (ICAR) – VC Farm scientists released two hybrid varieties over the course of the 1990s. Both KRH-1 (1994) and KRH-2 (1996) were designed to be well suited for the unique conditions present in Indian irrigated agroecosystems. Nonetheless, while both varieties showed greater tolerance to local pests and diseases than Chinese imports, the former variety was unable to demonstrate a strong yield advantage over the original Green Revolution rice Jaya and the latter was largely rejected by farmers in southern India owing to an aromatic quality that did not align well with local tastes.[3]

Hybrid rice development at VC Farms subsequently underwent a period of relative inertia and KRH-4 – which began development in 2007 and was finalised in 2012 – represented the first significant hybrid release since the flurry of the mid-1990s. For the production of KRH-4, two parent lines with desired qualities (MSN 36 and CRMS 32A) had been developed using standard breeding methods before being crossed, resulting in a medium duration variety that matures quicker (130–135 days) than some popular varieties such as Jaya. At the same time, KRH-4 is argued to produce superior grain yields of between 8 and 8.5 tons per hectare in controlled research conditions. This represents an improvement on the standard varietal checks used within the Indian testing system. Specifically, KRH-4 had a 17.82 percent yield advantage over the non-hybrid check (BPT 5204), and a 3.66 percent gain over the hybrid check (DRRH 3). For context, average yields within India are reported by IRRI to be in the range of 3.62 tonnes per hectare, although yields in the Cauvery region are considerably higher at around 5–6 tonnes per hectare under irrigated conditions (National Research Development Corporation 2016).

Beyond abstract yield potential, KRH-4 is argued to meet three other regional needs, making it a versatile addition to growing numbers of hybrid rice seed in the market. First, KRH-4 is a medium slender variety, similar in size and texture to popular consumption varieties within south India. Second, as a medium-tall plant, one of the promoted benefits of this variety is its straw yield, an important consideration for many farmers in the region that have cattle. Taller than the semi-dwarf HYV varieties, with a significant number of tillers produced by the heterosis effect, KRH-4 produces significantly more fodder than semi-dwarf HYVs. Third, the variety was shown through field tests to have acceptable tolerance of leaf blast, sheath rot, stem borer and brown plant hopper while also being moderately tolerant to salinity (National Research Development Corporation 2016). Indeed, KRH-4 passed all the national criteria for release through testing against standardised varieties (hybrid and HYV) in plots at zonal research stations across India. There is little doubt that KRH-4 represents a considerable technical accomplishment.

Notwithstanding its success in national testing, however, the release of KRH-4 occurred in a changing political economic context for public research in which private sector metrics are becoming increasingly dominant (see Sumberg, Thompson, and Woodhouse

[3]VC Farm scientists note that KRH-2 was well received and commercially successful in northern India where aromatic rice is the norm, as corroborated by (Janaiah 2002).

2012). For the university researchers who had developed KRH-4, there were strong pressures to translate success in national testing into a fully realised 'success story' of agricultural innovation through commercialisation. Indeed, this final stage of success making – validation through the sale of the intellectual property of the hybrid to private sector seed companies – has become a dominant measure of agronomic achievement. For the previous hybrid variety, KRH-2, researchers had made the technical details of the hybridisation process – including samples of the parental seeds – publicly accessible in order to maximise production of what they saw as a public good. Fifteen years later, however, there were strong pressures to adopt a sharply different approach. On the one hand, there is now a growing need for research departments to self-fund by creating revenue streams through the licensing fee and potential royalties from sales that accompany commercialisation. On the other, a number of private companies had produced the earlier variety KRH-2 using inferior production methods that created poor quality seed with disappointing yields. The ensuing cultivation of sub-standard KRH-2 in some areas damaged the reputation of the brand, including that of its public sector creators, and made researchers expressly keen to ensure the quality seed production for all future releases.

On this basis, it was decided to transfer the national-level production, distribution and sale of KRH-4 into the private sector through a tender process in which seed companies are invited to bid on the rights to intellectual property needed to produce the hybrid. Notably, the researchers themselves raised ethical questions about this process in which a publicly developed innovation would be sold off to a private sector seed company at a rate that – in their estimation – guarantees strong returns to the private sector while rewarding the public institution with only a fraction of the true costs of seed development. At the same time, they recognised that there was no in-house capacity to commercialise the seed at a national scale on their own terms. While VC Farm has the technical ability and production networks to cultivate hybrid seed in modest quantities for local usage, there was no longer a public sector means to scale-up production for national distribution. At the same time, researchers were already under considerable pressure to move swiftly onto new research priorities. Despite some misgivings, they had little choice but to let the National Research Development Corporation manage a commercialisation process on their behalf.[4]

Success making at the local level

While in 2017 university researchers anxiously watched the unfolding of the national tender process, the variety had been released locally five years previously. Using onsite production supplemented by contracts with select local farmers, KRH-4 was readily available for purchase through the main input merchant within Mandya, directly from VC Farm, and from local extension agents in rural towns who could order it at a subsidised rate (see Figure 1). In anticipation of the future commercialisation process, there was a pressing need for VC Farm to ensure that the initial local release of KRH-4 was deemed successful by demonstrating considerable interest for the variety among local farmers. In contrast to its hybrid predecessors in the 1990s, however, the social context that KRH-4 entered was

[4]At the time of research, negotiations over the commercialisation of KRH-4 had been on-going for longer than expected by researchers with the private sector reportedly seeking to strike a hard bargain.

that of an increasingly commercialised and competitive market for paddy seed. As Reddy (2017, 18) notes, across many parts of south India, the self-production of paddy seed by farmers has drastically reduced over the past decade leading to the collapse of many farmer-to-farmer seed exchange networks. The latter have been supplanted with a tendency to buy commercially produced seed on a yearly basis, typically from input merchants who distribute a range of varieties, from new and old HYVs to hybrid seeds. While there is a partial countermovement against this trend in Mandya – in the form of a return to traditional varieties grown without external inputs (Khadse et al. 2018) – the vast majority of farmers no longer save seeds while local input merchants sell dozens of commercial varieties. The main dealer in Mandya, for instance, had around 20 different rice varieties in stock.

At one level this extensive commercialisation facilitates the entry of new hybrids such as KRH-4 because it is no longer necessary to convince farmers to purchase commercial seeds. The majority are already doing so. At another level, however, the market for rice seed is now highly competitive with new varieties appearing in stores on an annual basis. Not only does this present formidable competition for market share, the pace of new varietal development has had important ramifications for the accumulation of agricultural knowledge among farmers (Flachs and Stone 2014). Faced with a bewildering array of commercial varieties, often marketed through poster campaigns in public venues (see



Figure 1. Sack of KRH-4 in local input dealer store.

Figure 2), many local farmers refer to hybrid rice seeds simply by the generic title of 'Jaya Cross'. They use this shorthand term because they are not familiar with the specific names of different hybrid varieties – even those they have planted – still less the particular qualities that any given variety is said to possess. On the contrary, given this shifting seed market, there is little opportunity for them to develop the medium term experiential learning necessary to build up a knowledge base around the relative attributes of different seeds. Instead, farmers either remain true to tried and tested older varieties or rely on outside sources of information to make seed choices presuming – correctly or incorrectly – that the latter are better informed about the best new varieties for local cultivation (Stone 2016). In Mandya, these tendencies are reflected in the way that smallholders are increasingly dependent upon: (1) the advice of local input dealers who have risen to be key local knowledge brokers within the agrarian environment despite their evident conflict of interest as commercial vendors (see Aga 2018); (2) contact with VC Farm extension agents, for those who can gain access to such networks; and (3) the influence of other farmers, with many farmers copying choices they see in neighbouring fields particularly among farmers who have local prestige.

In this context, for VC Farm to generate an initial success story for KRH-4, it was necessary to cut through these social constraints to promote what appeared to farmers as simply one more variety among many. Fortunately, as an agricultural university with its own dedicated extension department, VC Farm possessed longstanding channels for the diffusion of outputs that could aid in this task. To promote KRH-4 adoption, extension agents enrolled a series of local model farmers as intermediaries. The use of model farmers is a common extension strategy because it allows for both in-situ demonstrations of a new technology within villages and – if the model farmer has a significant prestige level – can guarantee strong initial buy-in among local farmers (Röling 1990). Equally, a knowledgeable and potentially innovative model farmer is more likely to be able to adapt a technique



Figure 2. Poster advertising hybrid seed on electricity poll in village centre.

or technology to local conditions than outside extension agents or researchers. That said, the use of model farmers as conduits of knowledge and inputs can consolidate existing rural hierarchies (Röling, Ascroft, and Wa Chege 1976; Taylor and Bhasme 2018a). In the present case, for example, the network was intrinsically gendered. It linked male researcher-scientists to male extension officers to male model farmers to male smallholders. Extension therein both reflected and reinforced entrenched gendered divisions of labour in which women were primarily seen as agricultural labourers in charge of the drudgery tasks of transplanting and weeding.

Notwithstanding these biases, by mobilising a network of model farmers supported with subsidised seeds and inputs, VC Farm sought to coordinate a rapid yet concentrated uptake of KRH-4 within selected villages. At one level, this strategy aimed to diffuse the variety regionally through a demonstration effect that could be amplified by publicity in local newspapers. Concurrently, it was also undertaken with one eye on generating a narrative of success to smooth a potential commercialisation process at a national level. Press releases – including two articles in leading English-language national newspaper *The Hindu* – promoted the virtues of the variety and claimed that it would lead to a 'white revolution' in the harvest season on the basis of a projected doubling of yields (Shiva Kumar 2012b). Farmers across Mandya and neighbouring districts, these articles suggested, were coming forward in considerable numbers to cultivate KRH-4 in over 5,000 acres of land (Shiva Kumar 2012a). Such accounts of a spontaneous rush to adopt an ideal new variety, however, obscured the coordinated nature of the extension efforts necessary to get KRH-4 into local fields. While the network of model farmers provided a swift route to set up demonstrations of KRH-4 cultivation, farmer adoption was spatially concentrated in villages where these networks were most embedded. Questions remained as to whether adoption would, first, outlast the initial subsidisation period within these villages; and, second, diffuse outwards among the smallholder population in general as hoped for by extension authorities.

One of the primary demonstration villages exemplified these tensions. At first there was a rapid trend towards adoption because a model farmer – who had been closely networked into VC Farm extension operations for over a decade – directly fostered the uptake of KRH-4 among an informal agricultural collective that he headed. With a close relative in the VC Farm research department, this educated and – in relative terms – more affluent farmer enjoyed a leadership role for this collective group composed of village smallholders who relied on him to establish seed choices and management practices on an annual basis. Without doubt, this mix of small and marginal farmers – all men – gained from this arrangement. They received close attention from a skilled and knowledgeable agriculturalist who used his unique relationship with VC Farm to deliver free KRH-4 seed and subsidised fertiliser over a four year period from 2012–2015. Given that input costs account for a substantial part of yearly cultivation expenses, this was of considerable benefit for smallholders as subsidies of this nature significantly lowered the risks involved in the annual cultivation cycle and reduced the need to take on debts for inputs at the start of the year.

Perhaps unsurprisingly, although these small and marginal farmers could answer little about the specific qualities of KRH-4 in comparison to other options, they responded positively about their experience with the hybrid. They were, however, clear that they relied upon the model farmer to make all key decisions in terms of seeds and management strategies, which raises questions as to whether these kinds of networks could promote lasting

adoption of KRH-4. Pertinently, at the close of the subsidisation period in 2015, the farmers in this collective stopped using KRH-4 en masse. The lead farmer suggested that changing varieties had been his choice driven to avoid the potential for the evolution of pests. While a change of seed might be a prudent move in some circumstances, the farmers were not reporting significant pest problems at that stage. Rather, the ending of subsidisation appears a more compelling motive for the change, particularly given that a large private sector seed company had approached the model farmer to act in a facilitating role for a new commercial hybrid variety. At the time of the interviews, the client smallholder farmers working in the model farmer's remit had switched to using private-sector seeds supplied through the medium of the model farmer and subsidised through a political agreement struck with help of the Agriculture Minister Byre Gowda. In short, adoption decisions were being determined by the political economy of agricultural networks and their associated subsidies, rather than the specific technical attributes of the seed varieties.

Outside of such a uniquely embedded network for strategic diffusion, KRH-4 adoption trends reflected a more general unwillingness of smallholders to take up hybrid seed. The majority of cultivators in the researched villages were small and marginal farmers working with between one to four acres, which comprise the vast majority of holdings and the majority of cultivated land in Mandya district (see Table 1). Among such interviewees, planting hybrid seed was almost universally viewed as an unattractive option. Their knowledge of KRH-4, moreover, was largely non-existent despite their villages being demonstration sites five years previously. For such farmers, the risks involved in switching to a relatively expensive and demanding crop appeared to be substantial. Hybrid seed costs significantly more than standard HYVs, which adds to input costs at the start of the year that are frequently covered through credit sources, typically from informal sources with high interest rates.[5] According to Kammardi et al., input costs in Karnataka account for over a quarter of cultivation costs and, when combined with low prices for agricultural output, often lead to marginal or negative returns for paddy (Kammardi et al. 2017, 51; see also, Sarkar 2017). At the same time, despite the allure of potentially increased yields to offset input costs, hybrid seed requires more complex management practices including the increased and more precise use of fertilisers alongside altered transplanting methods. Both of the latter add to the already significant cultivation challenges facing small and marginal farmers.

In addition, there were three specific aspects of the regional political ecology that pushed against hybrid use. First, with rainfall highly erratic for three years on a row – leading to considerable uncertainties over the provision of canal irrigation – many farmers from all social classes were keen to plant short duration varieties such as IR-64, and were unwilling to invest in the higher priced hybrids that might be wasted if drought persisted and irrigation failed. While extension agents were keen to combine KRH-4 use with a cultivation method known as the system of rice intensification (SRI) that needs less water overall, the complexities of the latter method presented additional challenges and risks for smallholders (Taylor and Bhasme 2018b). Second, small and marginal farmers typically use part of their paddy production for household consumption.

[5]In the neighbouring village of Alabujanahalli a socio-economic survey showed that, for small and marginal land owning households, between 61 and 81 percent of their outstanding loans came from informal sources (Bhavani 2017).

Table 1. Composition of Farms in Mandya District.

Category	Size (acres)	% of Total Farms	% of Total Land
Marginal	>2.5	75.6	44.6
Small	2.5–5	17.5	29.2
Semi-medium	5–10	6	19.2
Medium	10–25	0.9	6
Large	>25	0.04	1

Source: *Agricultural Census 2010–11* – Report on Operational Holdings in Karnataka, Directorate of Economics & Statistics, Bangalore.

Despite KRH-4 passing a taste threshold in national tests, local farmers complained that – like other hybrids – it was inferior in both taste and texture to established varieties and therefore did not provide them with the flexibility to shift between sale and consumption of their crop as circumstances dictated. Third, for farmers seeking a commercially viable crop with assured markets, cultivating Jaya – the original Green Revolution variety – provided a stronger option owing to established commercial networks that shipped the grain to Kerala and out to Gulf states for processing into food additives. Remarkably, a fifty-year-old variety of rice was still comprehensively outcompeting hybrids in terms of farmer choice on account of a better-established value chain.

These tensions between small and marginal farmer cultivation priorities and the demands of hybrid rice production were clearly revealed in a second village situated at the tail end of the canal system where reliable irrigation was increasingly tenuous. Among a relatively homogenous cohort of smallholders, most of who owned between 2 and 4 acres of land, an informal agricultural cooperative had been formed to coordinate knowledge sharing about suitable cultivation techniques. Headed by a prize-winning local farmer who enjoyed a longstanding relationship with VC Farm, this network had culminated in the site being designated as a 'model village' for the demonstration of agricultural innovations pioneered at the university. Working through the lead farmer, researchers had profiled a range of new agricultural technologies and management practices in the village, including plots of KRH-2 back in the 1990s through to KRH-4 in 2012. Notably, this village was profiled in media accounts as a success story in the regional release of KRH-4.

Despite the presence of this unique facilitating network, efforts to promote KRH-4 in the village had little lasting success, with total disadoption occurring after just two years. Reflecting on this experience, farmers stated a consistent opinion that hybrid seed exhausted the soil, a position that accords with the challenges of cultivating a plant that is designed to rapaciously draw nutrients form the soil to fuel its rapid growth. This reputation, along with significant uncertainties about water supply within the outlying channels of the canal system, led farmers to return either to planting commercial HYVs or move in a radically different direction towards revitalising traditional varieties. Strikingly, despite being the model village for intensive agricultural techniques promoted by university researchers, a subset of key farmers – including the lead farmer – had begun to cultivate traditional varieties of both rice and sugarcane in an explicitly low-input manner. In the context of a growing regional movement towards alternative agriculture (Bhattacharya 2017), a number of farmers were using a rice variety (*sidda sanna*) produced by a local cultivator and educator who explicitly rejected the use of both HYVs and hybrid seeds in general, and VC Farm priorities in particular.

Although these farmers were keen to argue that they had benefitted greatly from their longstanding relationship with VC Farm, there was nonetheless a tangible disjuncture between their official status as a 'model village' for agricultural intensification and the movement towards an agro-ecological approach to cultivation. This trend towards a less-chemical intensive form of agriculture was not driven by an ideological shift towards the environmental virtues of agroecological methods, but by the shifting political ecology that conditioned local livelihood strategies. Typical of villages in this region of Mandya, households rely on livelihood diversification to overcome the low remuneration and climatic uncertainties of agricultural income. While the vast majority of households maintain agricultural income as an important – either through direct crop production or agricultural labour – the vast majority of households in this area demonstrate an increasing reliance on income streams from members earning wages in manufacturing or in informal commercial activities (Bakshi and Das 2017). In particular, a number of textile factories had opened in the region that were employing a considerable number of younger women who previously had relied on agricultural labour. At the same time, commercial self-employment or labouring provided further income opportunities in village centres and in the city of Mandya located some 30 min away.

This meant that agriculture was increasingly serving a double function within livelihood strategies in which – typically – older household members continued farming to aid the social reproduction of the household through both direct food provisioning and by selling surplus to the market while younger members sought paid employment outside the village. For such purposes, a low-input agricultural strategy proved increasingly attractive as a means to reduce risks associated with changing rainfall patterns, shifting market prices for crops, and the high price that indebtedness for agricultural inputs placed on households (Khadse et al. 2018). In this context, farmers who had chosen the low-input approach argued that, using the knowledge support of the model farmer, they could achieve yields close to conventional methods yet with a fraction of the risks involved. Risk avoidance in the context of tight margins for agricultural production and growing uncertainties over access to water was therefore a key factor in determining seed choice for these small and marginal farmers. In contrast, the high input costs associated with hybrid rice appeared fundamentally incompatible with this household reproduction strategy.

In a third initial distribution site for KRH-4, a more diverse pattern emerged that reflected a different agroecological and social context. Located close to the Cauvery River, where irrigation was more dependable and more easily supplemented by groundwater, the cultivation of hybrid rice had become a small but discernable part of the cropping pattern among two distinct socioeconomic classes. First, a small number of commercially oriented farmers who possessed secure land and reliable irrigation were planting hybrids in several acres. Their hybrid of choice was not KRH-4 – of which they showed only a vague awareness – but a variety produced by a private seed company. A commercially oriented farmer had grown this variety with considerable success the previous season on plots that were clearly visible to other farmers from the main road. As is typical in the region, the farmer referred to the hybrid by the catchall title of 'Jaya Cross' and was initially unable to recall the specific name of the variety. Notwithstanding this uncertainty, the farmer had nonetheless achieved high yields in his first year of usage and made better overall returns than using HYVs despite higher input costs. In discussing

the challenges of hybrid cultivation, the farmer explicitly acknowledged the intensity of the input regime that accompanied their use. Hybrids, he noted, required three applications of fertiliser compared to the single dosage that he previously used with a standard HYV. He was able to adopt this new cropping regime after soliciting advice directly from state extension agencies regarding suitable inputs, an outcome that reflects better access to extension networks than many other farmers in the area.

This example of a commercially oriented farmer with irrigated landholdings and enough capital to invest in higher upfront input costs fits a well-established profile for leading adopters of new agricultural technologies (Chambers and Jiggins 1987). Other farmers in the village seeking to emulate his success, however, held a starkly divergent socio-economic profile. These consisted of a small number of young, landless male cultivators who had rented fields from absentee landlords to copy the above farmer's strategy of planting hybrids. They had done so, moreover, on all the land they had rented and without close connections to extension services, relying instead on asking other farmers for advice. This cultivation strategy ran counter to the cautious approach adopted by most smallholders in the village who were suspicious of hybrid use and preferred to maintain their reliance on familiar HYVs. For the landless cultivators, however, the strategy of hybrid cultivation was selected not because they felt they could afford to take on the risks of planting a more expensive and demanding crop in uncertain climatic conditions. On the contrary, it was because they felt they couldn't afford not to. With the price of land rental added to the costs of production and the cycle of debt repayment to informal lenders who they relied upon, these producers needed a high reward strategy regardless of the risk. Standard paddy production simply failed to offer a potential remuneration sufficient to cover those costs imposed on a landless class. Ironically, in an austere agrarian environment, a new class of risk-taking farmers appears to be emerging among precisely that marginal social class that is objectively least able to shoulder the risk.

Conclusion

In explaining the role of HYVs in the original 'Green Revolution', Norman Borlaug noted that seeds were merely the catalyst for a wider social transformation of agriculture. 'You have to support them with a total package of modern technology,' he insisted, 'and with strategy, with psychology and with firm, guaranteed economic policy from the government' (cited in Cullather 2010). This insistence on new seed technologies as a fulcrum for transformative agrarian change that is both material and cultural remains firmly embedded in the expectations placed on hybrid rice in contemporary India. While scientists emphasise how the heterosis effect inherent to hybrid seed technologies can raise yield ceilings, this attribute can only be fully realised within a broader package incorporating technically sophisticated cultivation strategies, intensive input regimes, and a deeper commercialisation of input provisioning. Hybrid seeds thereby encapsulate a modernising vision of agricultural intensification, one that is increasingly justified by neo-Malthussian concerns about food security in conditions of population growth alongside climate change impacts. In the Indian context, this sense of a brewing crisis has been amplified by the shadow of farmer suicides and an increasingly restive farmers' movement that has condemned widespread rural social distress on a national stage.

The ability of hybrid rice to act as a technical fix to such social malaise, however, is strongly questionable. Notwithstanding its institutional status as a key driver of a projected 'new Green Revolution', the national uptake of hybrid rice by smallholder farmers can only be described as hesitant and uneven. This pattern was reflected in Mandya district where hybrid uptake was marginal despite determined efforts by public-sector agronomists to create a high-performing variety suited to local agronomic conditions alongside focused extension strategies among local villages. Most pertinently, hybrid rice adoption remained frustrated in Mandya not in spite of its modernising imperatives, but precisely because of them. For many small and marginal farmers there existed a fundamental tension between the demands of hybrid rice cultivation and livelihood strategies that prioritised risk-aversion within an austere agrarian environment in which water availability was increasingly uncertain. While some farmers are indeed willing to take on the risks involved in hybrid cultivation – typically, but not exclusively, those with more reliable access to land, water and extension networks – hybrid rice was generally seen by smallholders as disconnected from their livelihood needs. Tracing the creation, diffusion and commercialisation of hybrid seed in this manner closely illustrates how new agricultural technologies can only be fully understood when the networks that facilitate their creation and diffusion are analysed within the wider political ecology of commercialisation, intensification and agrarian fragmentation. It is through these tense relationships that the hopes and expectations for a 'new Green Revolution' play out in contemporary India.

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