'Fields of plenty'
by Elizabeth Finkel

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It's 2063, and life is good. Technology has given Indian farmer Prabhjit Kumar the tools and seeds she needs to feed her family. But can the dream of sustainably feeding the world's nine billion other mouths be fulfilled? **Elizabeth Finkel** investigates.

FIELDS OF PLENTY

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PRABHJIT WAKES TO the sound of the roosters crowing, just like her mother, grandmother and countless generations of Indian women have before her. In the cool morning air, she silently wraps herself in a green-and-gold sari, washes her face and braids her hair. Peering into a dimly lit mirror, she daubs a vermillion bindi on her forehead, then sits cross-legged to meditate, returning the room to stillness. She concludes by kneeling at the small altar to Hindu goddess Parvati, lights the incense and utters a prayer.

But Prabhjit's next morning ritual is different. Moving into the living room, she passes her henna-tattooed hand over a picture of her 15-year-old daughter. Apoorva's image dissolves and eight farm grids sprout onto the screen, their colours every bit as vivid as Prabhjit's sari. Her practised eye homes in on the scarlet dots – in-field sensors, sitting among the crops like tiny one-eyed metal scarecrows – that alert her to two patches on the northwest corner that are in distress. They'll need a little more water. Then she zooms out to scan the satellite data from the entire area of Odisha state in eastern India. Some other farms have already begun their harvest; Prabjit begins ruminating about the implications. But the sound of an alarm clock pushes these thoughts to the back of her mind. Time for Apoorva to get ready for school.

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IT'S 8 AM, AND PRABHJIT is sitting in front of her data screen in the small office to the side of her living room. Her husband has taken their daughter to the village high school, and himself to the office; he is the chief hydraulic engineer at Ganjam city council. Prabhjit calls her foreman to tell him to increase the flow rate in the drippers for fields NW1 and NW2. He also needs to service the rice harvester ahead of next weeks' harvest, and while he's at it, the rice-transplanter and tractors, to ready them for leasing to her neighbours. She arranges to meet him for an onsite visit at 11 am.

There's a knock at her door. It's expected – the two-monthly visit from Anil, her 'ag-service' provider. She puts on a pot of chai and asks politely about Anil's family before they move on to some local gossip. Who's planting what, what are the pests like, and what's his take on the market? Then she steers the conversation to rice. Anil confirms what she already knows. Some farmers have started to harvest a bumper crop. But her crop needs another week to reach its peak. With plenty of rice on offer, will she get still get a good price? Or should she store her rice? Prabhjit weighs Anil's opinions, and decides to silo her harvest in the village granary and wait for the price to rise.

Then they chat about vegetables. Prabhjit's three-year contract for lentils and eggplants with the

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ARIEL JAVELLANA/IRRI

Rice paddies at the International Rice Research Institute, based in Los Baños in the Philippines, are home to rice varieties that contain the *sub1* gene. This gene helps rice tolerate flooding. Floods can devastate ordinary rice crops, causing shortages and raising prices of a grain that's a staple in many countries.

>> Bhubaneshwar grocery store is about to run out. Again, she gently questions Anil to find out what sorts of deals are being made. She decides to renew her contract, but on Anil's advice will try the latest variety of Ganesh BT+ eggplant, with its promise of a four-week shelf life.

Anil taps his briefcase, prompting a holographic display of the latest upgrade for satellite and field data. Prabjit can't resist and signs up. At 10.30 am, she heads to her meeting with the foreman. As she emerges from the cool of her rice husk-cement composite home, the Sun is beating down hard. She unplugs her car from the socket and eases herself into the drivers' seat... just in time to receive a call from her mother. After inquiring whether Apoorva remembered her morning prayers, Prabjit's mother reminds her that tomorrow is the anniversary of her grandmother's death – she and Apoorva should light a special incense stick. Prabhjit signs off a little abruptly. Yes mother – I need to meet with the foreman now. Talk to you later.

Prabhjit had intended to spend the 10-minute trip planning her conversation with the foreman. But as she cruises down the paved road, an unbidden image projects itself onto the swaying green fields on either side of the car. Shin-deep in a muddy paddy, Grandmother and Mother (then just 12 years old) are bent over, shuffling backwards. They are in the Punjab, far from home, labourers in a team of women who spend day after day poking rice seedlings into the mud. Weeks later they will make their way back home, exhausted, huddled under blankets waiting at the foggy, smoke-filled train station in Ludhiana.

Another image replaces this one. Grandmother and Mother are transplanting rice again, but this time it is their own paddy. And this time it is a special crop; it will change their future.

GRANDMOTHER MAY NOT have been able to read, but she could sense the winds of change. Her husband had long ago left the farm to work at a brick factory: the tiny payment the government broker provided for their rice harvest wasn't enough to make ends meet. Yet, the government was urging farmers in Odisha to plant more rice because the wells of the Punjab, as everyone knew, were running dry. Odisha was usually blessed with ample rain, but there could be drought. Or floods. Both had struck in the year before Grandfather left.

"The tools we have now for genetically tweaking plants are vastly superior."

One year, Grandmother was given some seeds when she attended a meeting at the village. The government woman in her fine blue silk sari had explained that the seeds, which had been developed in the Philippines and were called Sub1, were very strong. If a drought came, the seedlings would not shrivel up. And if the floods came, they would extend their tips, reaching up like tiny mouths above the water to breathe.

As Grandmother and Mother transplanted each seedling, they held it as tenderly as if it were a leaf >>

The Swarna Sub1 rice variety, pictured here growing in Chinsurah, India, is tolerant to drought as well as flooding. This multitalented grain will be a game changer in areas prone to both extremes.

With a combination of advanced breeding programs and genetic modification, new varieties of ancient grains may usher in the next Green Revolution.

ISAGANI SERRANO/IRRI

>> of gold. Their efforts paid off: that first year, the floodwaters covered their crop for two weeks, but the crop had not drowned and, unlike many of the other farmers in Odisha, they had made a nice profit. Three years later, Grandmother went to another meeting. This time, the lady in the fine sari introduced her to a new type of rice – she said it was the daughter of Sub1. But this daughter was 'smarter' than her mother, so they called it Super Sub1. Not only would this plant survive drought and flood, but it could also extract phosphate from the soil, so Grandmother would not have to spend so much on costly fertiliser.

Grandmother's profit rose steadily each year. She decided that, just as Super Sub1 was smarter than its predecessor, her daughter would be smarter than her. She could have put the profits toward her daughter's dowry as her husband and his family had told her to. But she didn't. Against their thundering disapproval she used the money to send her daughter to the agricultural college in Bhubaneshawar – the first of her family ever to finish high school, was now being sent for a college degree! Grandmother simply closed her ears to the cries that her daughter would never marry.

They were wrong. Mother married a man she met at the college. While looking after her babies, she also managed the farm accounts and read farming journals, sharing the latest news with father while the family feasted on her delicious curry and chapati. Prabhjit grew up hearing the story of the smart rice that paid for Mother to go to college.

By and large, the Malthusian spectre that haunted the world 50 years before – that the population would outgrow its food supply – failed to materialise.

In Prabhjit's teens, the winds of fortune brought more changes. One was the land reform. A new law allowed the formation of small farming corporations, up to 40 hectares in size. Prabhjit's father took his two hectares and joined up with Grandmother's two. It wasn't hard to rent more blocks – many of the families had moved to the city, leaving their old folk to work the paddies. It took years to finalise the negotiations; Prabhjit recalled Father tearing his hair and moaning: "It's just molasses, this Indian bureaucracy." By the time she graduated from college, Father left the running of the farm to her. She took a loan on microcredit to build up the farm to its present 24 hectares – and took the wheel.

THE OTHER REVOLUTION for Prabhjit was the genetically modified seed that allowed rice to 'fix' its own nitrogen from the Earth. She recalled her parents' eyes glowing as they told her about it. Like Super Sub1, this was a very clever seed. A worldwide project, funded by the legendary Lord Bill and Lady Melinda Gates, had taken nearly 50 years to develop it. As Mother loved telling the wide-eyed young Prabhjit, "these rice grains are the children of Lord Lakshmi, benevolent goddess of light, and Vishnu, the restorer". When Prabhjit reached high school, her mother gave her the scientific explanation. The rice plants had been genetically engineered to carry the powerful photosynthetic engine of a corn plant. But they also carried the nitrogen-fixing genes of a legume. Truly magical plants, they produced >>

THE DARK SIDE

MANY EXPERTS think food production will keep pace with population growth. What they fear is what will be done to the environment to achieve it.

The worst-case scenario sees large chunks of existing farmlands lost to erosion, salinity and urban development. The Amazon Rainforest will be lost to agriculture, accelerating the build-up of greenhouse gases. Farmers will be forced to use ever-higher levels of pesticides to control disease and pest outbreaks worsened by a cooking climate. Waterways polluted by fertiliser and pesticides will cause the collapse of fisheries.

There are plenty of factors conspiring towards this scenario. Despite rising food prices, farmers continue to operate on very slim margins, holding out for that fortunate year when they reap both a bumper crop and a good price. That means they need to keep their costs as low as possible, which means shortcuts. Richard Roush, dean of land and environment at the University of Melbourne frames this problem as "the tragedy of the commons". Farmers focus on short-term individual gain rather than the long-term common good. It's a predicament exacerbated by low food prices. Roush and colleagues at the University of California at Davis calculated that if farmers could charge just 10% more, they could afford to use the best environmental practices.

Fixing the economic settings for farmers is a global challenge. Take Australia's biggest grain farmer, John Nicoletti – long an icon as a successful farmer–entrepreneur. In 2011, he owned 180,000 hectares. In January 2013, it was down to 142,000 hectares and he was angling to sell a further 81,000. "There's just not enough money in the farming game anymore," he told *Farm Weekly*.

Since the 1970s, an area greater than 745,000 km² has been cleared from the Amazon Rainforest. The rate of deforestation has slowed in recent years, but areas are still being cleared for agriculture.

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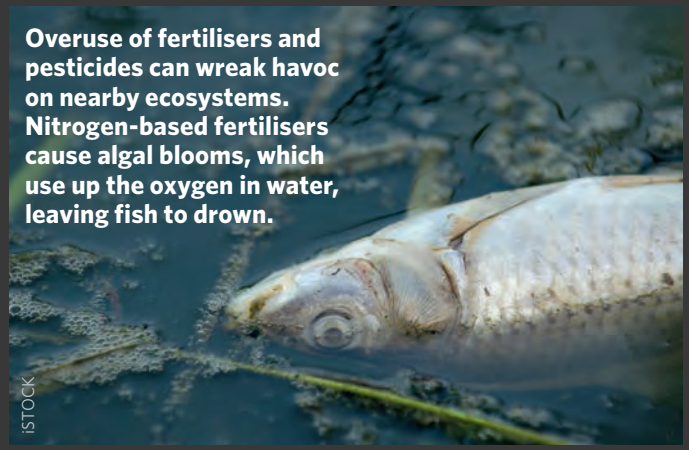
Another source of alarm is the declining investment in public sector research – the driving force for technologies that would enable a small-scale farmer like Prabhjit to farm more productively with a smaller environmental footprint. Philip Pardey, agricultural economist and director of the International Science and Technology Practices and Policy Centre at the University of Minnesota, St Paul, is worried that countries such as the U.S. and Australia have cut spending on research and development. "Australia is in trouble," he says. "Fifty years ago it ranked eighth in the world for R&D spending; now it's 16th." Pardy points out that it was the investments of 50 years ago that gave us the Green Revolution and averted the widespread famine predicted in the 1960s by ecologists like Paul Ehrlich. His research shows that 50 years is about the lag time before the investment in agricultural R&D fully delivers. In 2063, when climate change and bursting populations will make dire demands of agriculture, he worries we will not have "primed the knowledge pump". The signs are the pump is already running dry. "For years we saw rice and wheat yields rising," he says. "Surprise, surprise; now they have almost stopped."



Overuse of fertilisers and pesticides can wreak havoc on nearby ecosystems. Nitrogen-based fertilisers cause algal blooms, which use up the oxygen in water, leaving fish to drown.

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>> rice grains that were double the size using half the amount of fertiliser.

Vegetable seeds improved too: eggplants, cauliflowers, cabbages like the family had never seen. Best of all, they could throw away the most toxic pesticides because these seeds produced their own pesticides borrowed from the genes of a species of bacteria known as *Bacillus thuringiensis*, or BT for short. These vegetables were so powerful at resisting pests and raising profits, they earned the name 'Ganesh' after the elephant-headed son of Shiva, who was also the god of good fortune. Mother said they could have had Ganesh seeds years before. She never understood why the government delayed them; BT cotton had already saved millions of cotton farmers from pesticide poisoning and raised their yields. And BT was so safe, it was the stock-in-trade for organic farmers who sprayed the bacteria directly on their plants.

Prabhjit never forgot that gleam in her parents' eyes. And she never forgot Grandmother. She passed away when Prabhjit was 20; a shrunken 57-year-old. Now, not so far from that age herself, the realisation shook her. Grandmother withered from the backbreaking work planting rice and spraying pesticides from a perforated spout of two tin cans yoked across her neck, barefoot. She had told Prabhjit how they would come back from the spraying, sick with headaches and shakes. In her final years, she still suffered from them. Lying on pillows on the cot, she told Prabhjit her stories; the ending was always the same. Prabhjit clearly heard Grandmother's voice: "You will be like the rice grains that grow smarter in each generation." Grandmother, I will light the incense stick for you tomorrow and I will tell you how smart I have become, Prabhjit answered silently.

YOU MIGHT SAY Prabhjit's story is a dream. And you'd be right. It is the dream of plant pathologist Robert Zeigler, director of the International Rice Research Institute (IRRI) in Los Baños, Philippines. It's a dream that he has spent the best part of his career trying to turn into a reality. Many of Prabhjit's farming tools are in the development pipeline, and some have already emerged.

The flood- and drought-tolerant rice variety (named Swarna Sub1 by IRRI researchers) is already available. The variety that can mine its own phosphate from the soil (referred to as Super Swarna Sub1) is due for release in the next couple of years. It carries a gene called *PSTOL1*, which IRRI breeders managed to isolate from a traditional Indian rice variety that performs well in soils with low phosphate levels. Both these new rice varieties were developed through a 20-year process of shuffling genes from semi-wild or old-fashioned farmers' rice varieties into modern high-yielding ones by conventional breeding techniques.

The next cabs off the rank will take longer. Rice that can double its production by using the supercharged photosynthetic engine that naturally belongs to a corn plant is a tough ask – but one that's on the cards, and known as the C4 rice project. It involves retrofitting a whole assembly line of corn genes and redesigning the infrastructure of the rice plant to accept them. Another very tough ask is to ferry the genes of a legume into a cereal grass such as rice, maize or wheat, enabling the plant to 'fix' its own nitrogen. A crop like this would truly usher in the next Green Revolution; doubling yields but using far less fertiliser than today's rice requires. The Bill and Melinda Gates Foundation, enamoured of bold challenges, is funding both projects.

"The tools we have now for genetically tweaking plants are vastly superior."

What's the chance of success? I ask Zeigler. "Undoubted," he says. "When I proposed the flood- and drought-tolerant rice project 20 years ago, I was laughed off the stage. The tools we have now for genetically tweaking plants are vastly superior."

Not all the tools that might be available to someone like Prabhjit come from the whiteboards of IRRI. The satellite from which she downloads data traces its origin to European Space Agency Sentinel satellites, the first of which is scheduled to launch in 2013, and whose microwave beams penetrate through clouds, meaning they can provide data about rice crops in Asia throughout the cloudy monsoon season. But IRRI is developing the software to enable farmers like Prabhjit to benefit. And it won't just enable individual farmers to maximise their market opportunities – this type of data could help prevent a food price spike, says Zeigler. "With time to adjust to a shortage, they can import ahead of time, avoiding a panic."

Prabhjit also uses drippers to irrigate and fertilise her fields. Punching tiny holes in tubing to deliver water and fertiliser at a slow rate more than halves a crop's water requirements. Israeli inventor Daniel Hillel won the 2012 World Food Prize for developing it. Outside water-starved Israel, the fastest adopters to date have been China and India, countries that have increased their usage around 100-fold in the past 20 years.

In 2063, Prabhjit's world is a happy place. By and large, the Malthusian spectre that haunted the world 50 years before – that the population would outgrow its food supply – failed to materialise. The challenge, then, was to feed an anticipated extra two billion mouths using existing agricultural lands. And it's quite a challenge. In 2013, 38% of the world's ice-free surface area is already under the yoke of agriculture, about a third of it for cropping, the rest for grazing. This land is also being lost to erosion and salty soils, smothered by roads, houses and golf courses; and chunks of it are being carved off to grow biofuels rather than food. Add to that the threats to agriculture from climate change, declining water supplies, flattening yields for wheat and rice, dwindling sources of phosphate, rising costs of nitrogen fertiliser, poor commercial incentives for farmers – and it's clear why many are worried that the mid-21st century will be an age of mass famine.

But in Prabhjit's world, mass starvation has been averted – and the ecological health of the planet is >>

>> improving. In 2013, agriculture is the planet's biggest polluter. Clearing chunks of the Amazon for farming (and losing carbon sinks), burning fossil fuels to make fertiliser (using up to 1% of the world's energy); methane released by microbes fermenting in rice paddies and belching cows; and the nitrous oxide released by overuse of fertiliser, account for 35% of global greenhouse gas emissions. The same fertiliser running off fields into waterways causes algal overgrowths, sucking oxygen out of the mouths of the world's major rivers and creating 'dead zones' for fish. This and overfishing threaten the imminent collapse of the world's fisheries.

So can we address and remediate these problems? In October 2011, scientists led by Jonathan Foley, director of the Institute on the Environment at the University of Minnesota, published a manifesto in *Nature* entitled 'Solutions for a cultivated planet'. Foley's group offered a five-point plan to feed the planet without destroying it (see 'Saving the world', opposite).

As Foley concluded in an article in *Scientific American* published in November 2011: "Feeding nine billion people in a truly sustainable way will be one of the greatest challenges our civilisation has ever faced. It will require the imagination, determination and hard work of countless people from all over the world. There is no time to lose."

IT WILL TAKE MORE THAN the insight of farmers like Prabhjit's grandmother to bring this vision to a reality. In the scenario painted here, Prabhjit is environmentally aware and government incentives encourage her to employ 'best-practice' techniques. For instance, she drains her fields at the midpoint of the growing season rather than the end because (as IRRI research shows) this dramatically reduces methane emissions. For her trouble, she receives a carbon credit.

Elsewhere, highly mechanised and automated megafarms are the order of the day. For a taste of what's to come, take a look at the rain-fed wheat farms of Western Australia (WA), which stretch >>

SAVING THE WORLD

In 2011, a group of scientists published a bold five-point plan to meet the world's future food security and sustainability needs.

1 STOP EXPANDING AGRICULTURE

Land that is now covered in tropical rainforest, which is being cleared at a rate of around 5–10 million hectares annually, offers little yield when converted to agriculture. Protecting this crucial carbon sink from slash and burn agriculture for quick gains requires economic incentives such as carbon credits and market certification.

2 CLOSE THE YIELD GAP

By bringing under-performing farms in Central America, Africa, Asia and Europe up to speed with judicious use of fertiliser, irrigation and improved seed, Foley estimates that the yield of the world's top 16 food crops could be increased by 58%.

3 USE RESOURCES MORE EFFICIENTLY

Employ technologies such as drippers and so-called 'precision agriculture' where water and fertiliser are meted out in response to the day-to-day needs of the crop.

4 EAT LESS GRAIN-FED BEEF

Thirty-five per cent of crops are grown to feed animals, but when it comes to beef this is a terribly wasteful use of food: every kilogram of deboned steak comes at the expense of 30 kg of grain.

5 REDUCE WASTE

Roughly 30% of food is wasted. In affluent countries, it's mostly left uneaten on the dinner plate; in poorer countries, food spoils in the fields or in silos. The solution is to reduce portion sizes and improve storage and distribution systems. Smartphones could also help farmers reduce losses. In the past, with their crop in danger of rotting in the field, farmers were hostage to middlemen. With smartphones, they're free to search out the best price.

Can we feed nine billion people without cannibalising our planet?

KOSTYANTINE PANKIN/123RF

>> over tens of thousands of hectares. Here today, 500 horsepower, GPS-guided harvesters cut 25 m swathes of wheat, measuring the yield in each square metre as they go, and informing next season's fertiliser requirements. Unskilled drivers simply need to tell the harvester to turn around when it gets to the end of the field. But it's not hard to see an end to that requirement, says Mick Keogh, executive director of the Australian Farm Institute. Like the three-storey-high robot trucks that remotely mine the iron ore of WA, in 2063, robotic harvesters will dutifully bring in the wheat harvest.

In 2063, robotic harvesters will dutifully bring in the wheat harvest.

Further north, like other countries with vast rangelands, Australia sports thriving cattle farms – because here, the beef and dairy cows graze on lands useless for cropping. Here again, genetic resources could herald a revolution. In 50 years' time, the cows roaming the vast outback stations of Australia's northwest won't look terribly different, except for the tiny chips embedded in their necks to monitor their health and movements. But genetically they will be a breed apart. Improved methods of marking genes and the mapping of the cow genome will lead to breeds that easily withstand heat stress, thrive on grass and belch less methane. Meanwhile, pampered in their barns, healthy herds of dairy cows, freed of mastitis and other diseases of the past, are milked robotically, produce 50% more milk, and deliver a calf each year without birth complications.

Yes indeed, this version of 2063 is a happy place. But there is also a nightmare scenario that many experts fear is equally likely (see 'The dark side', p61). Let's hope the world instead follows Foley's prescription. There is, indeed, no time to lose.

Elizabeth Finkel is the associate editor of *COSMOS Magazine*.

Main image: Root nodules of *Medicago italica*, or hairy medick, a little flowering plant related to alfalfa. Classified as a legume, this plant has the distinct evolutionary advantage of extracting its own nitrogen from the soil – effectively self-fertilising – using a symbiotic relationship with bacteria such as *Rhizobium leguminosarum* (inset), shown here in a coloured scanning electron micrograph. Ferrying the genes that enable this nifty relationship into cereal grasses such as corn, rice or wheat would dramatically alter their fertiliser needs, heralding a second Green Revolution.

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