effective research. Indeed, the public and the private sector have been of mutual benefit in many areas—The SNP Consortium, where companies and academia make single nucleotide polymorphisms (SNP) data freely available, being an example. But, although there are many areas where both can co-operate, there are also areas where each sector must go its own way and therefore have the required infrastructure. 'If the public sector wants to have data freely available, then the public sector will have to pay for it—either directly or indirectly,' said Goodfellow. 'It would be unsustainable for commercial companies to conduct basic research if they could not commercially exploit the results.' Ploegh agrees: 'Certain things won't get done [in industry] for economic reasons [...] but that doesn't mean that the basic scientists have stopped working on it.' As an example, he cites the work on the anthrax edema factor that was of purely academic interest until the bioterrorist attacks with anthrax-contaminated letters in the US.

Perhaps the debate about what to support—large-scale data generation or curiosity-based research—is a sign that biological research itself is changing as it comes to rely increasingly on expensive technology. Again, physicists went through a development of this kind decades ago and eventually were able to convince politicians to provide the money for their expensive equipment. There is a solution to this, and that is simply increasing the money for research. Interestingly, the debate that is taking place in Europe is not mirrored in the US, where spending for biological and biomedical research remains at an all-time high and Congress has no objection to increasing the NIH's budget further. European policy makers are not oblivious to this solution either; in fact, at the recent summit in Barcelona, Spain, the Heads of States endorsed a proposal to increase the investments into research and development from 1.9 to 3% by 2010. Compared to what countries spend on defence or social security, this is only a minute amount of money to come up with. 'If you double the spending on science, it would not even register as a blip on people's tax forms,' said Nilsson.

'If the public sector wants to have data freely available, then the public sector will have to pay for it—either directly or indirectly'

Holger Breithaupt

DOI: 10.1093/embo-reports/kvf105

Growing greener

The impact of integrated pest management

In the fierce debate about genetically modified (GM) crops, both sides claim to protect the environment. Proponents of pesticide- and herbicide-resistant plants maintain that their use will actually decrease the need for chemicals in agriculture. Opponents claim that GM crops themselves endanger the environment and say that growers should adopt less toxic alternatives rather than rely on untested technology.

The fact is, however, that most farmers have already progressed from the indiscriminate use of chemicals in the 1950s and have adopted 'greener' alternatives. Many of these techniques form part of the increasingly popular integrated pest management (IPM) approach. In its broadest sense, IPM promotes action against pests only when necessary, choosing the most effective option with the least risk to people and the environment, and applying knowledge about pest biology to create long-term, prevention-based solutions. 'Growers have been very willing to adopt IPM programs since they see the value both in the marketplace and to the environment as well,' said Lorianne Fought, a plant pathologist with Bayer in Leverkusen, Germany, at the American Phytopathological Society meeting in Salt Lake City, UT, in August 2001. Most studies acknowledge that the use of IPM in general has clear economic benefits. But, although its use is widespread, IPM may be very expensive to administer and its long-term effectiveness is still unproven, she said. Furthermore, many critics and ecologists maintain that IPM is more a tool to increase farmers' returns than one to improve the environment. This calls for more research on IPM to identify potential weak spots and improve effectiveness if farmers are to continue to use this approach.

The idea of combining traditional means of pest control with those that aim for prevention rather than cure dates back to the late 1950s, but it gained momentum only after Rachel Carson's *Silent Spring* was published in 1962, which described how chemical pesticides cause serious harm to humans, wildlife and the environment. In addition, there was growing evidence of resistance to these and other chemicals in common pests, so many small and medium-sized farmers came to believe that the indiscriminate use of toxic chemical pesticides was not sustainable. IPM over the next 30 years became widely practiced and evolved from alternative to mainstream. A recent survey from the US Department of Agriculture (USDA) found that, on 70% of land used for farming in

The USDA found that, on 70% of land used for farming in the US, some form of IPM is employed

the US, some form of IPM is employed, which is comparable to the situation in Europe.

IPM programs vary according to location and users, but they all share the goal of reducing the use of chemical pesticides through techniques such as crop monitoring, crop rotation, maintaining and increasing biodiversity of the farm system, staggered planting, strip cropping, using disease-free seeds and plants, spacing of plants and altering planting dates. 'IPM [...] combines all practical methods of managing pests including biological, cultural, physical and chemical methods in a manner that attains the producer's production goals while minimizing economic, health and environmental risks,' said Thomas Fuchs, IPM coordinator at Texas Cooperative Extension in San Angelo, TX. 'It encompasses the pests, the crop and the environment, and spans the spectrum from chemically intensive to biointensive IPM, and everything in between.'

Unaffiliated crop consultants have at least a BA degree—though many also have advanced training—and their competancy and independence must be certified. Consultants in the extensive public IPM network connected to colleges and universities—many of whom are academics—have advanced degrees in either plant physiology or entomology.

Marvin Harris, Professor of Entomology at Texas A&M University in College Station, TX, investigated the use of IPM by Texan pecan, cotton, and sorghum farmers and found that it had a huge impact that went beyond profitability and the reduction of pesticides. The overall economic benefit to pecan producers was estimated by Harris to be $6.06 million. Environmental benefits include less pollution of the riversides, less energy use and less air, soil and food contamination. 'IPM has permeated the entire society, affecting public attitudes on how we want to conduct plant protection. In turn, these attitudes educate, research and implement solutions to pest problems, the industries that serve the process, and the legislation and agencies that govern quality food production and environmental health,' he wrote. 'Nevertheless without producer profitabilty, no agricultural program, no matter how meritorious in other respects, could succeed for very long.'

IPM has made a particularly significant impact in areas of high heat and humidity, such as Florida and Texas, because these conditions foster pest infestation. In Texas, IPM was introduced in four locations as a federal pilot program for cotton farming under the control of entomologists and now extends to 25 locations, dealing with 12 crops. Soon after IPM was introduced, yield was slightly lower, on average, than on conventional farms, but the number of pesticide applications on IPM farms decreased by 71%, use of nitrogen fertilizer decreased by 76%, irrigation decreased by 25% and total production costs decreased by 46%. Whereas conventional farms had a loss of $105 per acre, IPM farms showed a net profit of $81.50 per acre, according to Fuchs. By 1986, 82% of growers in this area were using scouting in cotton, a prime IPM method where pest populations and crop development are monitored, and they all reported higher yields, higher quality cotton as seen by higher loan prices, lower herbicide costs and received $111.20 more per acre than non-users.

Now, IPM is used on virtually every cotton farm in Texas. 'After the 1980s, direct comparisons of conventional versus IPM production became very difficult because almost all growers were using some components of an IPM system,' said Fuchs. A 1994 survey of 1522 cotton growers showed that they used a wide array of IPM practices: 89% scouted for pests, 84% used recommended planting dates, 85% used recommended plant populations, 69% considered natural enemies when making control decisions and 65% used insect- or disease-resistant varieties.

Fuchs separated the users into different levels of IPM implementation (high,

Environmental benefits include less pollution of the riversides, less energy use and less air, soil and food contamination

All reported higher yields, higher quality cotton as seen by higher loan prices, lower herbicide costs and received $111.20 more per acre than non-users

IPM is more a strategy than an industry, practiced and taught by many colleges and universities, as well as private companies. According to Allison Jones of the National Alliance of Industrial Crop Consultants, there are 2500 private consultants in the US, in addition to academics who may also act as advisors to outside groups. The private consultants monitor farmers' crops each week and make recommendations as to what other IPM strategies should be used. 'They may use GPS [geographic positioning satellite technology] and other more hands-on techniques to monitor fields, and with that, determine whether one part of a field is pest-ridden. If only one section is affected, they will recommend that only that section be treated with insecticides or other agents,' she said. In contrast, there are other crop consultants who are affiliated with specific seed or chemical companies; they give advice for free but sell their company's products, she noted.

medium and low), determined which practices were being used and gave farmers composite scores accordingly. He found that yields increased as IPM scores increased. Production costs per acre also increased, but costs per pound of cotton lint produced decreased. 'Based on this sample of growers, the data suggest that to take maximum advantage of the benefits of IPM, growers should use a high level of IPM.'

Texan pecan farmers are not as convinced about the benefits of IPM: only 40–50% of pecan growers use some IPM techniques successfully to ward off its major pests—pecan weevil and stink bugs—according to Bill Ree, a pest management expert at the Texas Agricultural Extension Service in Bryan, TX. But those who do use them reap greater financial benefits than when they had sprayed pesticides indiscriminately, he said. Methods include employing a growth-regulating compound that causes larvae to moult prematurely but does not kill beneficial ladybugs. Farmers also use trap cropping, which entails planting alternate host plants such as peas or soya on the perimeter of a pecan tree plantation to attract the pests away from the crop. And many farmers have reduced multiple sprayings to only 2–3 treatments in the growing season in areas with pecan weevil infestation, he said.

Elsewhere, Charles Mellinger, a plant physiologist and consultant with Glades Crop Care, Inc., in Jupiter, FL, showed that preventive measures to avoid pest infestations alone can produce considerable savings. Prevention is particularly important for tomatoes, as the chemical control for bacterial spot, the major disease of this crop, is only partially effective. 'In-field cultural practices for this disease are based primarily on crop destruction, volunteer control and routing of hand labour crews,' said Mellinger. 'But the greatest impact on bacterial spot management is actually during transplant production. It is at this point that avoidance/prevention practices which focus on sanitation can make the most impact.'

Mellinger analysed the costs of various preventive practices and then computed the total cost and gain/loss per acre. He found that by using low-tech, labour-intensive IPM techniques, which cost about half as much as the high IPM practices, the real cost of *not* performing preventive practices was $12 515.03 and $1705.03, respectively. 'While these steps may seem like a great addition to the cost of production, compare them to the cost of bacterial spot.'

Even so, IPM has not been without its share of criticism. In August 2001, an article in *Nature* by Jane Mammott and M. Laurie Henneman of the University of Bristol, UK, asked whether all IPM is benign or whether it may also lead to widespread environmental harm by altering the local ecology. Their study documented the use of non-indigenous plants and animals to fight pests in Hawaii and their interaction with native species to determine whether any adverse changes, either direct or indirect, occurred in the food chain. The authors describe the relationships between crops, the butterflies and moths whose caterpillars feed off the crops and their parasites, some of them non-native species introduced to control the pests. They collected 2000 caterpillars and found that 20% of them died from parasite attacks, mostly from non-native agents introduced for pest control. Immigrant wasps, which accidentally found their way into the food web, were the next most lethal group of parasites, whereas native parasites killed only 3% of the caterpillars. The researchers said that it was unclear whether the alien species eventually out-competed the natives or whether the latter were already few in number. What is certain is that some biological control agents in early programs left these habitats and became attacking native species elsewhere. They therefore stressed that it is critical to understand the ecology of a system before introducing biocontrol agents.

It is critical to understand the ecology of a system before introducing biocontrol agents

But introducing pests into a location and having the situation go awry is the exception and not the rule, according to Fuchs. As a safeguard, all such activity is regulated by USDA: farmers must register with the federal agency, stating what they are introducing into the environment; and, before this is approved, they must submit studies that demonstrate safety. If an agent is to be introduced from overseas, it must first undergo quarantine, and additional safety studies must also be provided. USDA therefore acts as a 'watchdog' to oversee the situation and intervenes when necessary.

For some critics, IPM simply does not go far enough. Katherine DiMatteo of the Organic Trade Association (OTA) in Greenfield, MA, and the Appropriate Technology Transfer for Rural Areas Organization (ATTRA) in Fayetteville, AR, maintains that IPM still remains pesticide-based and therefore is not a real alternative solution. 'Even with the adoption of IPM by some conventional growers, the US government has proven lax in its promises to address pesticide-related problems. Although it had pledged to implement IPM on 75% of total US crop acreage by 2000 to reduce pesticide use, statistics show pesticide use actually rose by 40 million pounds since 1992,' said her colleague Barb Haumann of the OTA. The USDA and the Environmental Protection Agency 'have done little to implement their 1993 pledge to get farmers to reduce pesticide use through the promotion of IPM programs', she concluded.

Furthermore, ATTRA maintains that IPM as it is practiced today has strayed from its original ecological basis, is reactive and is based on knowledge of pest infestations rather than a proactive approach that 'proposed to manage pests through an understanding of their interactions with other organisms and the environment'. At the same time, the number of organic farms is on the increase. The number of acres farmed organically doubled in the years between 1994 and

1997, according to DiMatteo, and she expects another doubling again since 1997. While only comprising about 2% of the land used for agriculture, organic farming accounts for large areas in certain locations, such as Vermont, where 24% of all vegetable production is organic. In Europe, this figure overall is around 3.4%. The OTA maintains that the demand for organically grown crops is on the rise; so too is public disdain for bioengineered crops. But it is only a niche market, and organic, environmentally friendly farming certainly comes with a higher price tag for the consumer.

A middle ground between IPM and organic could be 'biointensive or ecology-based IPM', which aims to decrease inputs of fuel, machinery and synthetic chemicals, according to ATTRA. Biointensive IPM takes a 'systems' approach and, as such, resembles the original concept of IPM that emphasises restoring and enhancing the natural balances in the ecosystem, not just the elimination of pests. For this approach, ATTRA warns against the use of synthetic pesticides, noting that they often cause resistance similar to that seen with the overuse of antibiotics and can actually lead to a resurgence of pests by killing off natural beneficial organisms. It advises creating habitats to enhance the reproduction of beneficial pests, so-called farmscaping, and the use of less toxic chemical pesticides such as soaps, oils, boric acid, sugar esters and pesticides derived from naturally occurring compounds such as pyrethrum, neem, rotenone and *Bacillus thuringiensis*. Perhaps this form of IPM will appease all parties and be the farming of the future.

Vicki Brower

DOI: 10.1093/embo-reports/kvf107

Injection of confidence

The recent controversy in the UK has led to falling MMR vaccination rates

The media love a whistleblower. Particularly with the current mistrust of science, one lone voice pitted against the majority of scientific opinion is guaranteed to grab the public's attention. And this is exactly what has been happening in the UK since a study in the April 2002 issue of *Molecular Pathology* (pre-published online in February) found that 75 out of 91 children with autism had traces of the measles virus in their gut compared to only 5 out of 70 healthy children. A striking statistic indeed, but the senior author of this paper has used this fact to promote his own unproven concerns that the combined measles, mumps and rubella (MMR) vaccine could be the trigger for the developmental regression in these children. Predictably, MMR uptake rates in the UK are falling, and some inner cities, particularly London, are witnessing their first measles outbreak for a decade.

The World Health Organization (WHO) aims to eradicate measles by 2007, but, in order to do so, it recommends that more than 95% of the population are vaccinated against the disease. Globally, the current average is 80% coverage; some countries, such as Finland, better that with a 99% uptake rate of the MMR vaccine, whereas France has 85%, Germany a meagre 70% and, with the current controversy, the UK's average rates are now falling from ~92 to 88% and are even down to 65% in some areas. This is in the face of a mounting body of

scientific evidence that this combined vaccine is actually one of the safest ever produced. Similar battles revolving around public confidence in vaccines have drifted in and out of the headlines in the past, but this trend in falling immunisation rates needs to be reversed before unnecessary deaths occur or the concern spreads beyond the UK or even to other vaccines. Hans Wilhelm Doerr, the Director of the Institute of Medical Virology in Frankfurt, Germany, commented: 'It seems to be the fate of every successful vaccination programme, that—if the infectious disease could be eradicated—the fear of adverse effects rises.'

Advances in modern medicine have been such that 10 diseases are now preventable by vaccination, requiring a total of 18 injections—some combined into a single jab—and three oral administrations by the age of two. Table I shows the immunisation schedule for the UK; although this is broadly similar for the US and the rest of Europe, each country has its own recommendations. Ironically, the success of these vaccines has led to a virtual elimination of these diseases in the developed world, and so parents are now questioning the need for these injections. But these infectious agents are all still very real threats in more developing countries—for example, 890 000 children die as a result of measles worldwide each year—and can easily be reintroduced through international travel and, potentially, climate change. Therefore, 'herd immunity' is required, where a sufficiently high