

Food Security and Climate Change: The answer is biodiversity

**A review of scientific publications on
climate change adaptation in agriculture**

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Climate change will profoundly affect agriculture worldwide. Food security in many countries is under threat from unpredictable changes in rainfall and more frequent extreme weather. Farmers in poorer countries with harsh climate conditions will likely be most affected.

A review of recent scientific literature underlines that the most effective strategy to adapt agriculture to climate change is to increase biodiversity. A mix of different crops and varieties in one field is a proven and highly reliable farming method to increase resilience to erratic weather changes. And, the best ways to increase stress tolerance in single varieties are modern breeding technologies that do not entail genetic engineering, such as Marker Assisted Selection. In contrast, there is no evidence that genetically engineered (GE) plants can ever play any role to increase food security in a changing climate.

Impact of climate change on agriculture and food security

Some of the most profound and direct impacts of climate change over the next few decades will be on agriculture and food systems (Brown and Funk 2008). All quantitative assessments show that climate change will adversely affect food security (Schmidhuber and Tubiello 2007).

Increasing temperatures, declining and more unpredictable rainfall, more frequent extreme weather and higher severity of pest and disease are among the more drastic changes that would impact food production (Parry et al. 2007, Kotschi 2007, Morton 2007, Brown and Funk 2008, Lobell et al. 2008). However, global trends mask tremendous regional differences, with the poorest being most at risk both by global climate variations and global commodity price fluctuations (Diaz et al. 2006). Some of the most important effects of global climate change will be felt among smallholder farmers, predominantly in developing countries (Morton 2007).

The latest Intergovernmental Panel on Climate Change (IPCC) report predicts the probability of more heat waves, heavy rainfall, droughts and other extreme weather throughout the 21st century (Parry et al. 2007).

Warming in the Indian Ocean and an increasingly “El Niño-like” climate could reduce main-season precipitation across most of Africa, East and South Asia, and Central and South America (see Figure 1) (Brown and Funk 2008).

It has been shown that by 2080, the 40 poorest countries, located predominantly in tropical Africa and Latin America, could lose 10 to 20 percent of their basic grain growing capacity due to drought (Kotschi 2007). The biggest problem for food security will be the predicted increase in extreme weather, which will damage crops at particular developmental stages and make the timing of farming more difficult, reducing farmers’ incentives to cultivate (Morton 2007).

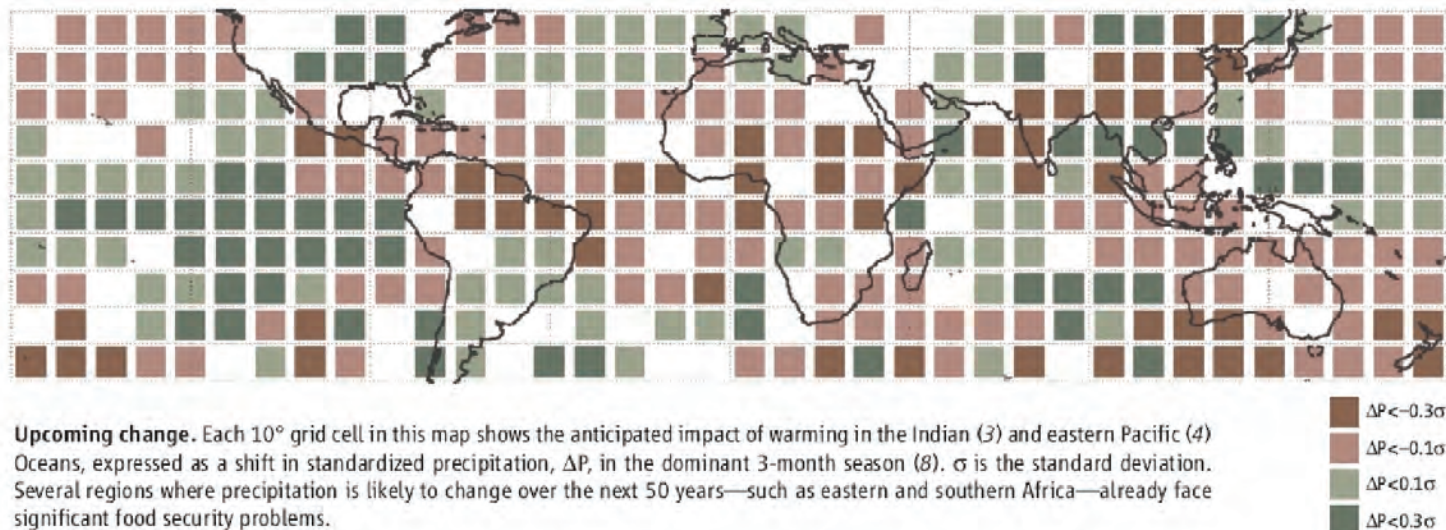


Figure 1. Projected upcoming changes in rainfall: **Red** grid cells indicate decrease in precipitation in the dominant 3-month season; **green** grid cells indicate increase in such precipitation. From: Brown, M. E., and C. C. Funk. 2008. Food security under climate change. *Science* 319:580-581. Reprinted with permission from the American Association for the Advancement of Science.

Biodiversity – a natural insurance policy against climate change

Diversity farming is the single most important modern technology to achieve food security in a changing climate. Scientists have shown that diversity provides a natural insurance policy against major ecosystem changes, be it in the wild or in agriculture (McNaughton 1977, Chapin et al. 2000, Diaz et al. 2006). It is now predicted that genetic diversity will be most crucial in highly variable environments and those under rapid human-induced climate change (Reusch et al. 2005, Hajjar et al. 2008, Hughes et al. 2008).

The larger the number of different species or varieties present in one field or in an ecosystem, the greater the probability that at least some of them can cope with changing conditions. Species diversity also reduces the probability of pests and diseases by diluting the availability of their hosts (Chapin et al. 2000). It is an age old insurance policy of farming communities to hedge their risks and plant diverse crops or varieties. The strategy is not to maximise yield in an optimum year, but to maximise yield over years, good and bad, by decreasing the chance of crop failure in a bad year (Altieri 1990).

This diversification strategy is backed by a wealth of recent scientific data:

- In a unique cooperation project among Chinese scientists and farmers in Yunnan during 1998 and 1999, researchers calculated the effect of diversity on the severity of rice blast, the major disease of rice (Zhu et al. 2000). They showed that disease-susceptible rice varieties planted with resistant varieties had an 89 percent greater yield than when they were grown in a monoculture. Mixed varieties of rice produced more grain per hectare than their corresponding monocultures in all cases; close to 20 percent more land is needed in a monoculture to produce the same amount of hybrid and glutinous rice as was produced in a mixture (Zhu et al. 2000). The experiment was so successful that fungicidal sprays were no longer applied by the end of the two-year programme. The practice expanded to more than 40,000 hectares in 2000, and now includes some varieties that were formerly locally extinct (Zhu et al. 2003). This is especially remarkable as the yield gains were on top of already high average yields in the region, at nearly 10 tonnes per hectare; among the highest in the world (Zhu et al. 2000). This shows that greater rice diversity means lower rates of plant disease and greater yields while conserving genetic diversity, all at minimal cost for farmers and the environment.

- Off the German coast, a genetically diverse area of seagrass was not only able to survive a heat wave, but experienced 26-34 percent more growth than seagrass monocultures (Reusch et al, 2005), showing how genetic diversity increases the ability for plants to recover after a perturbation, while genetic monocultures have a limited short-term ability to respond to extreme climatic events.
- In Italy, a high level of genetic diversity within wheat fields on non-irrigated farms reduces risk of crop failure during dry conditions. A scenario where rainfall declines by 20 percent, the wheat yield would fall sharply, but when diversity is increased by 2 percent, this decline can not only be reversed but above average yields achieved (Di Falco and Chavas 2006, 2008).
- Agronomists in the United States compared corn yields between fields planted as monocultures and those with various levels of intercropping in Michigan over three years. They found the yields in fields with the highest diversity (three crops, plus three cover crops) were over 100 percent higher than in continuous monocultures. Crop diversity improved soil fertility, reducing the need to use chemical inputs while maintaining high yields (Smith et al, 2008).

There is abundant scientific evidence that crop biodiversity has an important role to play in the adaptation to our changing environment. While oversimplified farming systems, such as monocultures of genetically identical plants, would not be able to cope with a changing climate, increasing the biodiversity of an agro-ecosystem can help maintain its long-term productivity and contribute significantly to food security. Genetic diversity within a field provides a buffer against losses caused by environmental change, pests and diseases. Genetic diversity provides the resilience needed for a reliable and stable, long-term food production (Diaz et al, 2006).

Analysis of past environment changes that resulted in dramatic famines (e.g. Ireland's potato famine and Ethiopia 1965-1997) shows specialised monocultures are highly vulnerable (Fraser, 2007).

In addition to enhancing food security and climate resilience, diversity in the field also delivers important ecosystem services. Variety mixtures that are tolerant to drought and flood not only increase productivity, but also prevent soil erosion and desertification, increase soil organic matter and help stabilise slopes (Hajjar et al, 2008). Benefits for farmers include reducing the need for costly pesticides, receiving price premiums for valued traditional varieties and improving their dietary diversity and health (reference, Hajjar et al, 2008).

The IAASTD on Climate Change

The International Assessment of Agricultural Science and Technology for Development (IAASTD), also known as the World Agriculture Report, was finalised in April 2008. This report, initiated by the World Bank and written by over 400 scientists from around the world, is comparable in its scope to the work of the Intergovernmental Panel on Climate Change. It reflects the global scientific community's views on agriculture and was endorsed by nearly 60 governments. In its Global Summary for Decision Makers, it states:

"To address expected climate change challenges and impacts, a major role for AKST [agricultural knowledge, science and technology] is needed to increase adaptive capacity and enhance resilience through purposeful biodiversity management. Options include irrigation management, water harvesting and conservation technologies, diversification of agriculture systems, the protection of agrobiodiversity and screening germplasm for tolerance to climate change."

In the IAASTD Synthesis Report, a specific section deals with climate change issues in agriculture and outlines the following adaptation options:

"- changing varieties/species to fit more appropriately to the changing thermal and/or hydrological conditions;

- changing timing of irrigation and adjusting nutrient management;

- applying water-conserving technologies and promoting agrobiodiversity for increased resilience of the agricultural systems;

- altering timing or location of cropping activities and the diversification of agriculture."

With regard to GE crops, the IAASTD global report, chapter 6, states: "Due to a combination of difficult to understand gene by environment interactions and experience to date with creating transgenic plants, some plant scientists are indicating that the rate at which transgenic plants will contribute to a sustained increase in future global food yields is exaggerated."

Modern breeding techniques for diverse genetic traits

In addition to increasing the diversity of crops and varieties in a single field, increasing the diversity of traits within one variety might help climate change adaptation. If each of the single varieties in one field has a higher tolerance to droughts, salinity, floods, storms and pests, the overall resilience to extreme weather events will be higher.

However, a review of the scientific literature reveals that the method of choice is not GE, but traditional and modern conventional breeding techniques, including Marker Assisted Selection (MAS). There is considerable scope for breeding a large number of stress traits through the use of traditional varieties. These stress traits are generally regulated by multiple genes, which in turn are tightly controlled by complex interactions between genes, and between the plant and its environment. MAS facilitates the selection of conventional crosses with traits associated with multiple genes, including their as of yet unknown regulatory systems. By contrast, genetic engineering can only crudely insert a single or a few gene(s) without any control over regulatory mechanisms.

What is Marker Assisted Selection?

Marker Assisted Selection (MAS, or Marker Assisted Breeding, MAB) is 'speeded up' conventional breeding that utilises knowledge of genes and DNA, but does not result in a GE organism. Specific DNA fragments (markers), which are closely linked to specific traits (such as drought tolerance), are identified. After crossing, the offspring is screened for the presence of the marker, and hence the desired trait, without the need to grow the plant under stress conditions. One important advantage of MAS over traditional breeding is that 'linkage drag', where unwanted traits are introduced along with desired traits, can be avoided. While MAS uses genetic markers to identify desired traits, no gene is artificially transferred from one organism into another one.

In recent years, MAS has yielded breeding successes, including some plants with traits that might be relevant for climate change resilience, such as drought, heat or cold resistant plants. However, it should be emphasised that none of these varieties alone will be able to contribute to food security in a changing climate. For erratic weather with rapid sequences of droughts, floods, storms and heat waves, only a mixed cropping system using a range of crops and varieties can provide the necessary diversity and resilience.

Some remarkable MAS successes:

- Rice tolerant to unpredictable floods. Rice production can be subject to stresses such as seasonal flooding, which can be unpredictable and can damage young rice plants. Through genetic mapping researchers identified a DNA segment containing a gene that makes rice tolerant to prolonged submergence in water (Xu et al., 2006; Sasaki, 2006). Using MAS, they successfully bred this trait into local and hybrid varieties. This allows the breeding of new varieties resilient to the erratic flooding that may occur as weather patterns become less predictable.
- One expected effect of climate change is the spread of disease. A new strain of wheat stem rust (Ug99), a fungus that can devastate wheat crops, is spreading across Africa. Most cultivated wheat varieties are susceptible to this virulent strain and efforts are underway to develop resistant wheat using MAS. The technique was chosen over GE (Durable Rust Resistance in Wheat, 2008) due to MAS's ability to assist the breeding of complex traits. The breeding programme will use wheat's genetic diversity to find resistance genes that can be bred into high yielding varieties. This shows the importance of preserving the genetic diversity of crops, which are at risk because modern intensive agriculture relies on very few varieties.

Even Monsanto, the global genetic engineering giant, features this breeding technique in its R&D brochure and states under the heading 'Marker Assisted Breeding': "Today, the use of breakthrough technology has reinvented plant breeding so we can more than double the rate of 'genetic gain' in seeds – the improvement in important characteristics such as yield and tolerance to environmental stress." Monsanto (2008a)

These examples are evidence that it is possible to transfer plants' complex traits, including their regulatory systems, to commercial varieties using traditional breeding techniques assisted by genetic markers. In contrast to this, GE plants have so far failed to deliver on any of the decade-old promises on stress tolerance. Instead, current GE varieties are particularly susceptible to extreme weather.

The limits of genetic engineering

So far, GE crops are restricted to a few traits that were developed some 20 years ago: herbicide and insect resistance. No stress tolerant GE plants have ever been proven to work under real world conditions. The performance of existing GE varieties under climate stress is so far sobering:

- Extreme temperature fluctuations caused crop losses in Bt cotton in China. Researchers investigating the disaster said high temperatures (37 C) were most probably responsible for causing a drop in Bt concentrations in leaves (Chen et al, 2005). Other researchers found that temperature changes, especially a cool period early on in the growing season, caused a reduction in the insect toxicity of Bt (Gunning et al. 2005).
- GE herbicide-resistant soybeans suffered unexpected losses in the US during very hot spring weather in 1998. Roundup Ready soybeans performed significantly worse than conventional varieties under conditions of heat stress. The GE soybean stems were more brittle and split more easily, thus allowing infection to enter (Coghlan, 1999).
- Herbicide tolerant GE soybeans currently on the market have been reported to have decreased yields of up to 10 percent compared to traditional varieties (Elmore et al, 2001). Massive herbicide use in conjunction with these GE plants has already led to an increase in tolerant weed populations (Nandula et al, 2005). For example, 34 cases of glyphosate resistance in nine species have been documented in the US since 2000 (www.weedscience.org). Now it is recommended farmers have to spray stronger formulas of herbicides (Monsanto, 2008b), and mixtures of herbicides (Brooks, 2003), adding to costs.

Even if GE might be able to deliver a heat tolerant plant in 10 or 20 years, what would happen to the plant under extreme cold conditions, unseasonable rain or drought? A single gene does not provide protection against a multitude of conditions.

Currently, most GE stress tolerant plants in the pipeline use a rather crude approach of over expressing a single gene throughout the plant's life cycle (Garg et al, 2002). This approach is no match for the whole genome network that controls gene expression in natural plants, where genes are switched on and off and moderated throughout the plant's lifetime. By contrast, the inserted gene in the GE plant is on all the time, in all parts of the plant, with no other control. It is like an air conditioner always running at full speed – which could prove deadly in winter.

In summary, GE plants:

- Will provide no security against extreme weather changes. In a best case scenario, they may be resistant to a single stress, such as heat or drought, but not to the expected rapid and radical weather changes;
- Will lack any sophisticated regulation of the inserted gene and thus cannot respond to changing challenges;
- Because of their higher price, they will most likely be planted in monocultures, which have the highest risk of failing in changeable and extreme weather.

Given genetic engineering's limitations and our limited knowledge about plants' regulated response to environmental stress, unregulated single-trait GE crops are a threat to food security in a changing climate. The prospect of large monocultures of GE plants failing completely under unforeseen weather events is a recipe for disaster.

Conclusions

Bio-diverse farming is a proven, effective strategy to adapt to climate change. Through it we can create farms that are able to maintain and increase food production in the face of increasingly unpredictable conditions. In contrast, GE has inherent shortcomings pertaining to plant-environment interactions and complex gene regulations that make it unlikely to address climate change either reliably or in the long-term. This conclusion is also reflected in the recent IAASTD report, which considered GE crops to be irrelevant to achieving the Millennium Development Goals and to eradicating hunger.

Agriculture will not only be negatively affected by climate change, it is a substantial contributor to greenhouse gas emissions. By reducing agriculture's greenhouse gas emissions and by using farming techniques that increase soil carbon, farming itself can contribute to mitigating climate change (Bellarby, J. et al. 2007). In fact, many bio-diverse farming systems are both mitigation and adaptation strategies, as they increase soil carbon and use cropping systems that are more resilient to extreme weather.

In order to increase our food security in a changing climate, policy makers need to follow the IAASTD's recommendations and invest more in agricultural R&D that is geared towards modern, effective, bio-diverse farming. A one-sided focus on GE plants contradicts all scientific findings on climate change adaptation in agriculture, and is a long-term threat to global food security.

References

- Altieri, M.A. 1990. Agroecology. In: Agroecology (eds Carrol, C.R., Vandermeer, J.H. and Rosset, P.M.) 551–564. McGraw Hill, New York.
- Bellarby, J., Foereid, B., Hastings, A., Smith, P. 2007. Cool farming: climate impacts of agriculture and mitigation potential. Greenpeace International, The Netherlands. <http://www.greenpeace.org/international/press/reports/cool-farming-full-report>.
- Brooks, R.J. 2003. Saving glyphosate. Farming Industry News, 1 February. http://farmindustrynews.com/mag/farming_saving_glyphosate/index.html
- Brown, M.E., and Funk C.C. 2008. Food security under climate change. *Science* 319: 580-581.
- Chapin, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C. and Diaz, S. 2000. Consequences of changing biodiversity. *Nature* 405: 234-242.
- Chen, D., Ye, G., Yang, C., Chen, Y. and Wu, Y. 2005. The effect of high temperature on the insecticidal properties of Bt cotton. *Environmental and Experimental Botany* 53: 333-342.
- Coghlan, A. 1999. Splitting headache: Monsanto's modified soya beans are cracking up in the heat. *New Scientist*, 20 November, 25.
- Di Falco, S. and Chavas, J.-P. 2006. Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. *European Review of Agricultural Economics* 33: 289-314.
- Di Falco, S. and Chavas, J.-P. 2008. Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. *Land Economics* 84: 83-96.
- Diaz, S., Fargione, J., Chapin F. S. and Tilman, D. 2006. Biodiversity loss threatens human well-being. *PLoS Biology* 4: 1300-1306
- Durable Rust Resistance in Wheat 2008. Project Objectives. <http://www.wheatrust.cornell.edu/about/>
- Elmore, R.W., Roeth, F.W., Nelson, L.A., Shapiro, C.A., Klein, R.N., Knezevic, S.Z. and Martin A. 2001. Glyphosate-resistant soybean cultivar yields compared with sister lines. *Agronomy Journal* 93: 408-412.
- Fraser, E. 2007. Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change. *Climatic Change* 83: 495-514.
- Garg, A. K., Kim, J.-K., Owens, T. G., Ranwala, A. P., Choi, Y. D., Kochian, L. V. and Wu, R. J. 2002. Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses. *Proceedings of the National Academy of Sciences* 99: 15898–15903.
- Hajjar, R., Jarvis, D.I. and Gemmill-Herren, B. 2008. The utility of crop genetic diversity in maintaining ecosystem services. *Agriculture Ecosystems & Environment* 123: 261-270.
- Hughes, A.R., Inouye, B.D., Johnson, M.T.J., Underwood, N. and Vellend M. 2008. Ecological consequences of genetic diversity. *Ecology Letters* 11: 609-623.
- International Assessment of Agricultural Science and Technology for Development (IAASTD) (in press) www.agassessment.org.
- Kotschi, J. 2007. Agricultural biodiversity is essential for adapting to climate change. *GAIA - Ecological Perspectives for Science and Society* 16: 98-101.
- Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., and Naylor R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science* 319: 607-610.
- Mackenzie, D. 2007. Billions at risk from wheat super-blight. *New Scientist*, 7 April, 6-7.
- McNaughton, S.J. 1977. Diversity and stability of ecological communities: a comment on the role of empiricism in ecology. *The American Naturalist* 111: 515 –525.
- Monsanto 2008a. R&D pipeline at a glance. <http://monsanto.com/products/pipeline.asp>
- Monsanto 2008b. http://www.monsanto.com/monsanto/ag_products/crop_protection/products/roundup_power_max.asp. Roundup PowerMAX™ is advertised as “proven on hard-to-control weeds such as velvetleaf, lambsquarters, purslane, kochia and morning glory”.
- Morton, J.F. 2007. Climate change and food security special feature: the impact of climate change on smallholder and subsistence agriculture. *Proceedings of the National Academy of Sciences* 104: 19680-19685.
- Nandula, V.K., Reddy, K.N., Duke, S.O. and Poston, D.H. 2005. Glyphosate-resistant weeds: current status and future outlook. *Outlooks on Pest Management* 16: 183-187.
- Nitta, T. 1991. Diversity of root fungal floras: its implications for soil-borne diseases and crop growth. *Japan Agricultural Research Quarterly* 25: 6–11.
- Olsen, K.M., Daly, J.C., Finnegan, E.J. and Mahon, R.J. 2005. Changes in Cry1Ac Bt transgenic cotton in response to two environmental factors: temperature and insect damage. *Journal of Economic Entomology* 98: 1382-1390.
- Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E., (eds.) 2007. Summary for Policymakers. In: *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, 7-22.
- Reusch, T. B. H., Ehlers, A., Hammerli, A. and Worm, B. 2005. Ecosystem recovery after climatic extremes enhanced by genotypic diversity. *Proceedings of the National Academy of Sciences*, 102: 2826-2831.
- Sasaki, T. 2006. Rice in deep water. *Nature*, 442:635-636 (news article).
- Schmidhuber, J. and Tubiello, F.N. 2007. Global food security under climate change. *Proceedings of the National Academy of Sciences* 104: 19703-19708.
- Smith, R.G., Gross, K.L., and Robertson, G.P. 2008. Effects of crop diversity on agroecosystem function: crop yield response. *Ecosystems* 11: 355-366.
- Xu, K., Xu, X., Fukao, T., Canlas, P., Maghirang-Rodriguez, R., Heuer, S., Ismail, A.M., Bailey-Serres, J., Ronald, P.C., Mackill, D.J. 2006. Sub1A is an ethylene-response-factor-like gene that confers submergence tolerance to rice. *Nature*, 442: 705-708.
- Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., Fan, J., Yang, S., Hu, L., Leung, H., Mew, T. W., Teng, P.S., Wang, Z. and Mundt, C.C. 2000. Genetic diversity and disease control in rice. *Nature* 406: 718-722.
- Zhu, Y.Y., Wang, Y.Y., Chen, H.R. and Lu, B.R. 2003. Conserving traditional rice varieties through management for crop diversity. *Bioscience* 53: 158-162.



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