



IWREC

International Conference  
Linkages between Energy and Water Management  
for Agriculture in Developing Countries

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ABSTRACTS

**Water for food, energy and the environment?**

Keynote address 1: Peter G. McCornick (Director IWMI Asia)

The Comprehensive Assessment on Water Management in Agriculture has concluded that rather than a global water/food crisis, the world will be able to feed itself in the year 2050, but that the choices made in the near future will determine what the extent of the impact of this will be on the wider environment. Yet, while there may not be a pending crisis at the Global scale, without appropriate interventions, there will be crises at National and regional scales, especially in those countries where the 1/3 of the world's water-short population now lives. The location, frequency and severity of these crises will depend on many factors, including what interventions are made in the near future to address the challenges.

The upward trend of energy costs and concerns regarding the effects of climate change has reinvigorated the interest in alternative energy, including bio-energy and, more specifically, bio-fuels. The emerging interest in bio-fuels and bio-energy in general further complicates the demands on water, especially in the locations that are already water short and where other conditions, such as economic growth in parts of Asia, or under investment in infrastructure, is putting additional pressure on the availability of water resources. In these locations, it is necessary to consider the relationship between water, food, energy and the environment, and how evolving conditions can be utilized to create more opportunities for livelihoods rather than increasing poverty.

The example of the Krishna basin in which Hyderabad is located is particularly instructive. Already there are complex direct linkages between agriculture, energy and water- including hydropower, groundwater pumping and lift irrigation systems, all of which as will be discussed in this conference. As it now stands, the water resources of the Krishna basin are effectively fully allocated, and further uses of the water mean that in drier years, water will not be available to meet all existing uses. One of the drivers which has led to the current state of affairs has been the development of a sugarcane industry-a major biofuel crop, although in India it is primarily a food crop. The Krishna's

three riparian states, Andhra Pradesh, Karnataka and Maharashtra are in the top six sugar producing states in India, which is the second largest producer in the world. The growth of sugarcane is understandable given that it is one of the more water productive (dollar per cubic meter) crops (Gaur et al, 2007), but further expansion will place increased pressure on a basin that is already under stress.

The water, agriculture, energy and environment setting is quite different in Ethiopia, a country beset by regular droughts that require regular emergency food imports. Ethiopia has amongst the lowest energy consumption per capita in the World, with more than 95 percent of this in the form of biomass, primarily fuelwood, dung and crop residues. Because of increasing rural population, the demand for biomass has escalated to the point where less than 3% of the natural forest remains (Seleshi, 2007), fuelwood is short and the lands in the highlands, where the majority of the population resides, is degraded.

Among other things, this energy crisis has reduced the water holding capacity of the soil, significantly modified the hydrology, and accelerated erosion, which causes problems downstream, including silting of the hydropower reservoirs, which are responsible for supplying the majority of the remaining energy consumed in the country. The degraded catchments also increases the risk for extreme events downstream (droughts and floods), and reduced bio-diversity.

Rather ironically, in addition to significant opportunities to increase the productivity of the agricultural sector, Ethiopia has enormous potential for energy production, particularly hydropower, which is estimated to be 100 times the current installed capacity. There are ambitious plans to develop hydropower (and other energy sources) to meet domestic needs, but also to export electricity to Djibouti, Kenya, Sudan and, through the proposed Eastern Nile Power Interconnection project, to Egypt and even Europe. To this end, there are a number of major dams either under construction or at an advanced stage of planning. There is also growing interest in utilizing land and water resources for bio-fuels, with a plan to develop 200,000-ha for rainfed agriculture in the south west (Bekele, 2007).

The Krishna and Ethiopia present two contrasting examples of the complex relationships between water, food, energy, and the environment. In the Krishna there are already significant investments in water resources management but a growing economy is placing increasing stresses on water resources, and further energy needs have to take account of the existing limitations. On the other hand Ethiopia has an energy crisis of a very different nature that is also closely linked to water and land resources, yet the country has the potential to greatly improve the access to energy using its abundant water and land resources. A major challenge is implementing these developments in a manner that improves the livelihoods of the rural poor.

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## **Bio-energy, food and water use interrelationships. FAO's views**

Keynote address 2: Alexander Müller

Assistant DG, Natural Resources Management and Environment Department, FAO

Energy prices influence the food and agriculture sector in several ways. Classical macroeconomic effects affect all aspects of production, consumption and trade, and the costs of the energy-intensive inputs like fertilizer and fuel have more direct effects on production agriculture. But energy prices can also impact agriculture by creating new markets for those products which can be used as biomass feedstocks for the production of biofuels as substitutes for the petroleum-based fuels (petrol, diesel). They can also raise the competitiveness of agricultural products like cotton or natural rubber, that compete with oil-based synthetics whose cost rises with the price of oil.

Growing biomass for the production of either food or biofuels requires a substantial use of natural resources. The energy provided by the sun is free, but the process of photosynthesis that turns this energy into biomass requires a huge amount of land and water. The total yearly global photosynthesis is estimated to be around 8 times as much as the total yearly energy supply and, theoretically, a big part of this could be made available for energy. The technical and economical potential of biomass is of course far less. Assuming current yields, technology and crop composition, it is estimated that an area bigger than half of the current total global crop land would be required to meet today's needs for transport fuel only.

Globally there is still land that is potentially suitable for agriculture; around one third of the total land suitable for agriculture is currently under cultivation. Especially in developing countries there is still quite some land potential for expansion of agriculture. The main crops used for bio fuel production are sugar cane, sugar beet, cassava and maize for ethanol production, and palm oil, rapeseed and soybean for the production of bio diesel. Of these crops the sugar crops are the most water demanding and therefore the main crops that are grown under irrigation. The land potential for sugar beet can be found mostly in the temperate climate zones where sugar beet is regularly cultivated under supplementary irrigation (especially in the USA). Sugar cane is often grown in tropical areas under full control irrigation. Most of the land potential for cultivating sugar cane can be found in Latin America and Sub Saharan Africa where there is also the biggest water potential. In both areas less than 5% of the total available renewable water resources are being used, indicating a substantial potential for water use if compared to the more than 50 % in the regions of the Near East and South Asia.

At present the promotion of biofuels is often used in several industrialized countries as alternative to conventional food crops, to relax market constraints. But in the future it can have far-reaching effects on world agriculture as it can offer novel development opportunities for countries with significant agricultural resources. Africa, with its significant sugar cane production potential, is often cited as a region that could profit from Brazil's experience and technology, but obstacles to realizing it (infrastructure, institutional, etc.) should not be underestimated.

Given the uncertainties about future oil prices, the potential of world agriculture to become a significant source of feedstocks and the implications for the environment and food security situation, cannot be fully understood. However, it is likely that most environmental concerns shall be raised with regard to land expansion (e.g., deforestation and encroachment on pasture land), loss of biodiversity (e.g., due to monocultures) and increased water demand where irrigation is required. Apart from this, a significant increase in the production of biofuels might affect food security for the poor negatively, since food prices are likely going to rise because of resource diversion towards the production of feedstock crops for biofuels.

## Water management is an energy problem: mixing water with oil

Keynote address 3: David Zilberman (UC Berkeley)

Water systems are energy intensive as water conveyance and pumping demand significant amounts of energy. Modern irrigation technologies require energy for extra pressure. Increased water supply through the use of desalinization is also energy dependent, but the global energy situation is subject to much pressure and uncertainty. On the one hand, there is concern about climate change and a desire to reduce emissions of greenhouse gases. On the other hand, rapid economic growth in China, India, and other developing countries will lead to substantial increases in energy demands.

The increased scarcity of energy will have both direct and indirect implications for water. The direct effect will come from higher energy prices, which will result in a higher cost of pumping, conveyance, and desalinization. A higher cost of water will put pressure on water utilities, resulting in increased prices for consumers and a growing demand for reform that increases the efficiency of water systems. These impacts will also increase the value of water conservation activities. As we argued before, reform is triggered by crises; and while drought provides one type of crisis, high energy cost is another type of crisis that will trigger change.

The indirect effect will be in the form of demand for alternative fuels. We have already seen the increased production of ethanol and biodiesels, and these technologies can be improved upon and likely to become an important part of agriculture. Biofuels are attractive because they are feasible, and they are net contributors of minimal amounts of carbon to the atmosphere (they sequester carbon production). They provide new sources of income to farmers. The productivity of biofuels needs to improve from current levels, and new biotechnology tools can provide a big boost. The use of new crops such as switch grasses and techniques to convert celluloids to ethanol can enhance biofuel supply. As crops for biofuel become a major product of agricultural land, there will be pressure to increase the productivity of traditional food crops that will be allocated to reduced amounts of land. That may lead to higher food prices and increased land values that may negatively affect the poor. This possible negative impact can be partially mediated if the pressure on food systems will lead to increased emphasis on research of food production and better utilization of new technologies including biotechnology. Until the early 1900s, significant amounts of land were allocated to produce energy for transportation. The 20<sup>th</sup> century reduced the land allocated for this purpose because of cheap fossil fuel. In the future we may need to reallocate land for energy production.

# Water Trading in an Era of Increasing Energy Prices

David Zilberman (UC Berkeley)

In many parts of the world, water systems are energy intensive. Water systems include three elements: extraction, conveyance and distribution, and use. Extraction requires pumping, or in some cases, desalinization, which are energy-intensive activities. Conveyance facilities, like the large canals of the California Central Valley Project, require significant amounts of energy to elevate water and to distribute it for use. Irrigation systems also consume energy.

Increasing (sometimes doubling, or tripling) energy prices affect the basic economics of water systems. They significantly increase the cost of operation, and these additional costs are either absorbed by taxpayers, or transferred to the end-user. The financial pressure is likely to lead to consideration of institutional reforms and technological changes.

Our analysis will show that under various assumptions, increased energy prices are likely to lead to adoption of efficient extraction technology, improvement of canals and distribution systems to reduce conveyance losses, enhance the introduction of water trading and transition from water rights to water markets (to increase the efficiency of water use), and result in adoption of improved irrigation systems, as well as reduction in acreage of low value crops. We will develop an analytical model of water systems that will consider the impacts of energy price changes under different assumptions about water and water system ownership and control, and illustrate the results using figures from California.

A related issue addressed in this paper is the increased demand for water, resulting from the introduction of biofuels. This added demand will further intensify the pressure to increase efficiency of available water resources, and may actually lead to increased water extraction, while at the same time leading to a reduction of agricultural production and the conversion of land and other natural resources to biofuel production. We will demonstrate that the introduction of improved seed (including genetically modified) varieties can reduce some of the pressures associated with increased energy scarcity, especially their impact on consumers through increased food prices.

## Linkages between Energy and Water Management for Agriculture in Developing Countries

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Ladies and gentle men! Good morning to you all! I hope you all have had a pleasant trip to ICRISAT-Patancheru and I extend a hearty welcome to you all to ICRISAT campus and to this important meeting.

Those of you are visiting for the first time ICRISAT Campus, I recommend you to take a round around the campus during your visit. It is a lovely campus, which is as an exemplar of self sufficiency for water as well as maintaining the natural resources in the agro-ecosystem on a sustainable basis. The whole 1300 ha area is treated as a watershed and most of the rainwater is harvested from the run-off in the fields as well as rainwater from the building roofs including glass houses is harvested and conserved for use during the year.

You experts in the area of water and energy are here to discuss linkages between energy and water management for agriculture in developing countries I would take it little further to include poverty in this association. For sustainable development and to achieve the first millennium development goal of reducing poverty in half by 2015 through sustainable development is a massive task.

Water, energy, poverty or water security, energy security and prosperity, all are interlinked and we need to look these issues together while discussing water, energy and agricultural production and poverty reduction objectives, particularly with reference to developing countries.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), one of the 15 Consultative Group on International Agriculture Research (CGIAR) centers has a dual mandate i.e globally we are entrusted with the responsibility of conservation and genetic enhancement of sorghum, pearl millet, groundnut, chickpea and pigeon pea, that are important components of livelihoods of the poor of the semi-arid tropics (SAT) and in the SAT we have the mandate to manage natural resources on sustainable basis while improving livelihoods. ICRISAT's vision to 2015 is improved well-being of the poor of the SAT; and our mission is to reduce poverty, enhance food and nutritional security and protect the environment of the semi-arid tropics by helping to empower the poor through science. Being crops of the SAT region, ICRISAT mandate crops use relatively less water and are adapted well to low rainfall situations. Secondly, ICRISAT's genetic enhancement research focus is to improve their productivity in drought prone conditions—meaning producing more crops per unit of water thus helping to contribute to the preservation of water and energy resources. Thirdly, ICRISAT adopts an Integrated Genetic and Natural Resource Management (IGNRM) approach to manage natural resources on a sustainable basis for improved livelihoods by following R4D principles while yet protecting the environment.

There is strong correlation between energy consumption and gross national product as well as use of non-renewable energy and development. For example, developed countries

rely more on non-renewable sources of energy whereas developing and under developed countries rely more on renewable sources of energy for their needs. However, with the depleting reserves of fossil fuels, uncertainty of supply from restricted geographical regions and rapidly fluctuating prices of oil have brought bio-fuels into the central agenda of most of the countries for achieving energy security. However, in the quest of achieving energy security we also need to take into account food security as well as environment and sustainability issues in our thinking.

In the developing world, current water use efficiency for food production in irrigated areas and dryland areas is very low. There are a number of ways through which water use efficiency can be improved and energy consumption can be reduced for food production. For example, in rainfed areas through in-situ conservation of water. If we can retain more water in the soil and reduce energy consumption for pumping and transporting of ground and surface water for agriculture we can save energy as well as enhance water use efficiency for food production. Our experiences throughout the rainfed areas in India have shown that these soils are not only thirsty but also hungry: Not only for macro-nutrients like N, P and K but also for micro-nutrients like Zinc, boron, and sulphur. Simply by amending deficiencies, nutrient productivity of rainfed agriculture can be increased by 40-70% and with improved management practices by adopting an Integrated Watershed Management (IWM) approach we have shown that the productivity of rainfed areas could be doubled in a number of benchmark watersheds in 5 countries in Asia.

So how we can enhance the rainwater use efficiency for production from cultivated lands as well as for energy plantations from low quality, wastelands through appropriate management options.

ICRISAT is addressing the issues of bio-fuel crops in two separate ways. One is diversifying the uses of a crop like sorghum for ethanol production and rehabilitating the wastelands with non-edible oil tree plantations for bio-diesel production.

Furthermore, diversification of crop use, and identifying and introducing bio-fuel crops should result in increased farmers' incomes, thereby contributing to the *eradication of extreme poverty* (MDG 1) in rural areas helping 75% of the world's 2.5 billion poor (who live on <US\$ 2 per day), and contributing to their energy needs without compromising their food and feed security. It also helps in developing public and private sector partnerships—global, regional, national and local, which address MDG 8 (*global/regional partnership for development*).

Bio-fuels are currently based on the generation of ethanol from sugars or starch derived from sugar-rich juice, vegetative biomass or grain; or bio-diesel from the more direct use of edible and non-edible plant oils and animal fats (Ortiz et al. 2006). Ethanol accounted for about 90% of total bio-fuel production (39 billion liters) in 2005 ([www.commodityIndia.com](http://www.commodityIndia.com)) in the world. There is a large demand for ethanol to be blended with petrol (up to 25%, and without the need to modify engines), but the present molasses and sugarcane based ethanol production alone cannot meet the total requirement. Sweet sorghum is an excellent alternative in this situation owing to its shorter duration, wider adaptability, low cost of cultivation, and low water requirement to supplement current molasses and sugarcane based ethanol production. Sweet sorghum is well adapted to SAT areas and is more water-use efficient (310 kg water/kg dry matter)

compared to maize (370 kg water/kg dry matter) to convert atmospheric CO<sub>2</sub> into sugars, which makes it a most promising bio-energy crop. Therefore, ICRISAT is following the following approach—genetic enhancement of sweet sorghum cultivars for sugar rich stalks and high juice and biomass yield. We are also incubating the use of sweet sorghum as bio-ethanol feedstock for commercial utilization through public and private sector partnerships. Of course, there are other bio-ethanol feed stocks such as cassava, etc., on which other CGIAR institutions and NARS are working. ICRISAT research also addresses the development of high biomass low-lignin, brown midrib sorghums to serve as feedstock when the second-generation lignocelluloses-based ethanol production technology picks up on a commercial scale.

Secondly, on the bio-diesel front, ICRISAT in its integrated watershed management approach is undertaking rehabilitation of common property resources as well as degraded private lands using *Jatropha*, *Pongamia*, Neem and other non-edible oil plants. The main bottleneck in the area of non-edible oil production is that these crops are under-researched for commercial production.

The main areas which needs attention in this regard are:

- Assess genotypic variability for oil content and yield
- Breeding of high yielding (oil and yield) cultivars of *Pongamia* and *Jatropha* and other non-edible oil trees
- Suitable agronomic practices need to be determined
- Assess the potential of these crops as commercial crops in block plantations
- Training of various stakeholders for raw material production and processing.
- Suitable institutions and policies to ensure that common property resources can be developed for the benefit of vulnerable groups

The ICRISAT watershed team has developed a participatory model to rehabilitate degraded CPRs to the extent of 300 ha in two villages using a novel mechanism of putting landless people in groups and ensuring they receive the usufruct rights from the tree plantations on common lands in Andhra Pradesh.

ICRISAT is also working in the area of public-private partnership to establish linkages between farmers and a processing company: Southern Bio-technology online through a GTZ supported project in Nalgonda district of Andhra Pradesh.

In summary, we need to address the links between water, energy and poverty together taking into account not only technical and market issues but also the social and institutional aspects.

I am sure through this international conference on linkages between energy and water management for agriculture in developing countries, you will refine the research agenda for bio-fuel including bio-ethanol and bio-diesel through your deliberations during the next two days. I urge you that you use the next two days to come up with a blue-print for efficient ways of producing energy through crops improvement and water management practices for increasing crop productivity suited to a range of target environments.

Finally, remember our core business is agricultural and we should strive hard to enhance the water use efficiency in agriculture production by all possible means so that we need to use less energy.

## Global Scenarios for Biofuels: Impacts and Implications

Siwa Msangi, Timothy Sulser, Mark Rosegrant, Rowena Valmonte-Santos and Claudia Ringler (IFPRI)

In recent years, bioenergy has drawn attention as a sustainable energy source that may help cope with rising energy prices, but also maybe provide income to poor farmers and rural communities around the globe. Rising fuel prices, growing energy demand, concerns over global warming from GHG emissions and increased openness to renewable energy resources, domestic energy security, and the push for expansion into new markets for crops in the face of world trade outlooks are all factors driving interest in expanding bioenergy use. Despite keen interest in this sector, there are currently few players in this field: In 2005, Brazil and the United States together accounted for 99 percent of global ethanol production, whereas Germany and France accounted for 69 percent of global biodiesel production. However, developing countries with tropical climates may have a comparative advantage in growing energy-rich biomass; and second-generation technologies could enable expansion of the range of feedstock used from the traditional sugarcane, maize, and rapeseed to grasses and trees that can thrive in less fertile and more drought-prone regions. Potentially adverse impacts from a rapid bioenergy expansion include upward pressure on international food prices, making staple crops less affordable for poor consumers; potentially significant adverse impacts on both land (soil quality and fertility) and water resources; and on biodiversity and ecosystems, in general.

Given the numerous and high level of uncertainties regarding future biofuel supply, demand, and technologies, the paper examines three alternative scenarios: a conventional scenario, which focuses on rapid global growth in biofuel production under conventional conversion technologies; a second generation scenario, which incorporates a 'softening' of demand on food crops due to 2nd generation, ligno-cellulosic technologies coming online; and a 'second generation plus scenario', which adds crop productivity improvements to the second generation scenario, which essentially further reduce potentially adverse impacts from expansion of biofuels.

Results from the analysis show a potential food and water-versus-fuel tradeoff if innovations and technology investments in crop productivity are slow, and if reliance is placed solely on conventional feedstock conversion technologies to meet future blending requirements of fossil fuels with biofuels. This situation changes considerably with increased investments in biofuel conversion and crop productivity improvements. To mitigate potentially adverse impacts from aggressive increases in biofuel production therefore requires a renewed focus of crop breeding for productivity improvement in wheat, maize and even sugar crops. While some crops may be more favorable from the perspective of profitability, they may encounter binding environmental constraints, in particular water, for example, for sugarcane in India, and wheat or maize in Northern China. And even where water might be available, other natural resource constraints, such as land availability can constrain expansion, such as in Southern China.

Impacts of global biofuel development and growth on rural poor can be both positive and negative. Biofuel crops do not necessarily crowd out food crops, at least not under the alternative scenarios examined here. Instead there is room for complementarities and synergy and rural agricultural development and socioeconomic growth can go hand-in-hand with enhancement of bioenergy production capacity.

## **Biofuels: implications for agricultural water use**

Charlotte de Fraiture, Yongsong Liao, Mark Giordano (IWMI)

Rising energy prices, geopolitics and concerns on the impacts green house gasses emissions on climate change are increasing the demand for biofuel production. At present the estimated biofuel production is 35 billion liters, still a small part of the annual consumption of 1200 billion liters of gasoline worldwide. But the contribution of biofuels to energy supply is expected to grow fast.

Energy produced from biomass has many beneficial implications including reduction in greenhouse gasses, improved energy security, income source for farmers and greater energy efficiency compared to fossil fuels. On the other hand biomass production for energy may compete with food crops for scarce land and water resources. Already water scarcity is a major constraint in agricultural production in many parts of the world. Among others India and China, whose energy consumption is growing rapidly, initiated programs to boost biofuel production. Yet, both countries already face severe water limitations in agriculture.

Sugarcane, the crop mostly used in bioethanol production, is a water intensive crop typically grown under irrigated conditions. Adverse impacts of large scale irrigation expansion and associated monoculture on ecosystem services are well documented.

This paper explores the water implications of increased biofuel production under different energy scenarios, using the WATERSIM model. It concludes that the large scale production of biofuels tend to be water intensive and may aggravate water scarcity related problems, unless alternative crops are used.

## Business in the world of water scenarios

Joppe Cramwinckel (Senior Sustainable Development Advisor  
Shell International Exploration and Production B.V.)

Water is everybody's business. For us in the energy business it is timely to understand how water plays a role in energy development to ensure that we can be prudent global citizens, providing energy as clean as possible while taking good care of the natural resources. As a first step we have been using a scenario tool. The H<sub>2</sub>O scenarios offer three stories – H, 2, and O – about the role of business in relation to the growing issue of water in the world. These stories do not try to cover everything but attempt to bring to life a limited number of alternative future environments that will challenge our economic viability, social legitimacy, and global fitness in the marketplace.

**Hydro** is the story of *efficiency* (more value per drop and more drops for less). It highlights avoiding or unlocking legacies inherited from the past – in ways of thinking as well as in technologies, business practices, and public policies – to create new business opportunities in the world of water..

**Rivers** is the story of *security* – enough water of sufficient quality for both the haves and the have-nots. In this story, cast in the form of a cautionary tale, business recognizes that there are many different sides to security. Some businesses increasingly risk losing the 'license to operate' where they are competing with basic human needs or are out of touch with political realities. The story focuses on the '2' of H<sub>2</sub>O – 2 sides of the water question; 2 sides of a water dispute – often, literally, on opposite banks of a river that divides one territory from another or between upstream and downstream interests; 2 ingredients for meeting future water needs – market-driven solutions and far-sighted government policies; and, most importantly, the necessity of solving water problems '2-gether', in partnership with other stakeholders.

**Ocean** is the story of *interconnectivity* – accounting for the sustainability of the whole system. It focuses on how business begins to recognize its role in a world of bigger, more complex, interconnected, and dynamic water challenges and natural systems in which economies, societies, cities, and individual human lives are embedded. In the world of Ocean, business realizes that it cannot help particular communities survive and prosper at the expense of causing water stress elsewhere. Ocean is a world that offers new opportunities to help societies and governments achieve more inclusive and integrated forms of security. Like the entirety of the ocean, the enormous whole round 'O' of the H<sub>2</sub>O scenario is difficult to see, much less to act in relation to –but if we could imagine.

There are some actions the energy business can or should undertake. The Hydro scenario focuses on the requirement water efficient energy technologies. Water must be therefore be recognized as a constraint and integrated in innovation processes. The River scenario highlights the importance of knowing your water footprint. To anticipate where engagement is required to secure its activity, the energy business should understand its present and future footprint. The Ocean scenario highlights the need for connecting the dots between land, energy, water and climate to create opportunities the energy business would otherwise remain blind to. This requires concerted action among various sectors.

## **Water consumption and productivity of biofuels, native vegetation and other crops: Potential contribution of Remote Sensing**

Chris Perry (WaterWatch)

The potential for bio-fuels to contribute viably (that is with no subsidy, or with subsidies set to reflect the environmental benefits of reduced CO<sub>2</sub> emissions) is not a simple analysis. First, bio-fuels are competing with a product whose price has varied by a factor widely in the last five years. Second, bio-fuel plantations take some years (at least 2 years, often 5 or more) to become established and productive. Third, the “performance” of these crops—that is the yield per unit of land and yield per unit of water is not well documented. This paper reports remote-sensing based techniques that can substantially improve understanding of the likely impact of large-scale agricultural production of bio-fuel crops on local water balances. It is shown that remote sensing can assess changes in local water consumption compared to other land uses (including both irrigated and rainfed areas) as well as providing estimates of yield per hectare and the water consumption required for various yield levels.

Remote sensing techniques can be applied at various scales (5m up to 250m resolution) and can be used, based on archived data, to monitor performance over time—for example during relatively wet and dry years.

Such an analysis would provide valuable information for the assessment of the potential of bio-fuels in eastern Africa—and indeed elsewhere. Reliable information could be assembled regarding average productivity, and its variability, at field scales; the sensitivity of production to water availability; the necessity (or otherwise) of irrigation to support (a) establishment of bio-fuel plants and (b) maintenance of mature trees; and the consumption of water by bio-fuel plants compared to native vegetation (thus assessing whether “downstream” water users will receive more or less runoff following development of bio-fuel areas).

The point of departure for this paper is thus that the availability of water is likely to be a determinant of the success of bio-fuel investments and the impact of bio-fuel developments on other water users. Overall, such impacts will depend on markets, relative prices between various inputs and outputs (especially food and fuel), government policies and of course climate change. However, large-scale investments in bio-fuel plantations may have significant impacts on water availability for other users and a narrow analysis of these relationships can contribute to the broader assessment of biofuel impacts.

## **AQUACROP: The new FAO field-crop model for biomass prediction**

Pasquale Steduto (Chief of the Water Service, Land & Water Division, FAO, Rome)

FAO is in the progress of revising the *Irrigation & Drainage Paper n. 33* (Yield Response to Water) after more than 25 years from its publication. The Paper 33 represented a milestone in the FAO literature and it is still in use worldwide.

Nevertheless, considering the scientific progress in the domain of crop-water relations occurred from the time of the publication, recently there has been a demand for its update. During the last few years, a team of climate, crop, soil, irrigation, and water scientists and experts from various countries and research centres, including CGIAR, gathered regularly under the auspices of FAO to discuss the concepts, the development approaches and the implementation tools for re-addressing the “*yield response to water*”.

A clear distinction has been made between “tree-crops and vines” and “field-crops”. For the field-crops a revised modelling approach has been developed, evolving from the same fundamental relationship, linking crop production to water use as in the FAO Paper n. 33, but separating soil evaporation (the non-productive component of water consumption) from transpiration (the productive component of water consumption), and by expressing the final crop yield via its two major components, i.e., biomass and harvest index.

The concepts as distinguished has been implemented in the new FAO field-crop model, named *AquaCrop*. Some of the most significant peculiarities of are the following: (i) the *biomass water productivity* (or biomass water use efficiency) relationship is at the core of the model *growth-engine*, which is classified as *water-driven*; (ii) a climate normalization procedure allows to extrapolate growth simulations throughout locations and seasons; (iii) in terms of soil water balance, the model capitalize a few features already present in CROPWAT; (iv) it has many links with external toolkits and facilities already made available by FAO (e.g., *ClimWat*, *ClimAgri*) and with other helpful functionalities in the public domain; (v) it contemplates all possible water availability conditions (rainfed, and supplementary, deficit, and full irrigations), nutrition, salinity, capillary raise and few other conditions typical for marginal lands; (vi) it has a strong capability for prediction on crop responses under future climate change conditions; (vii) the model lends itself for both single and mixed cropping, including under-utilized crops; (viii) it serves planning, management and scenario simulations. Its sound scientific basis lends *AquaCrop* to perform at its best when used to predict biomass.

Although grounded on basic and complex biophysical processes, *AquaCrop* uses a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. The FAO field-crop model *AquaCrop* distinguishes from all other models present in literature for its optimum balance between simplicity, accuracy and robustness, addressing mainly practitioner type of end-user such as those working for extension services, governmental agencies, NGOs and various kinds of farmers associations. *AquaCrop* is also particularly suited for perspective studies involving water use in agricultural field crops.

As at the beginning of 2007, *AquaCrop* is not yet released for public use since it last version is being tested, calibrated and validated from several research institutes from all over the world. Its public utilization is expected for 2008.

## **Dualism from a Natural Resource Perspective: Water, Agriculture and Urbanization in China**

Fredrich Kahrl and DAVID ROLAND-HOLST (UC Berkeley)

China's meteoric economic growth has achieving improvements in living standards that defy even the most optimistic expectations held by its people a generation ago. These unprecedented gains have been accompanied by serious market failures in natural resource allocation, however, with implications that threaten the scope and sustainability of China's new prosperity. Nowhere is this dilemma more apparent than in patterns of water use, where the momentum of growth is challenging China's ability to develop, sustain, and allocate resources effectively. Rapid urbanization is a primary accelerator of water demand, while China's still dominant rural sector retains its responsibility as the world's largest food producer.

Because of competing resource needs, some observers fear a violent collision between these two essential sectors of the modern Chinese economy. Like the classical development debate over dualism and labor migration, this reflects concern that both urban and rural development are jointly constrained by economywide resource endowments, locked in a fixed-sum growth game. China certainly faces major challenges in water allocation, but two arguments can be posed against the most pessimistic views. Firstly, the experience of the Green Revolution and its aftermath demonstrated that productivity growth in agriculture can more than offset the effects of rural labor exodus. Second, much of China's present day water demand patterns have evolved without the disciplinary benefits of market forces. Under prevailing market and regulatory systems, scarcity and adverse externality effects have little or no economic recognition on an incremental basis. Thus private agents fail to adapt until shortages or crises emerge.

For both these reasons, the scope for policy intervention to resolve China's sustainability dilemma is considerable. This will require a combination of market reforms and commitments to public investment and R&D, all of which are essential to improve individual and allocative efficiency. In this paper, we survey current trends in rural and urban water use, with particular reference to its influence on China's growth prospects. In doing so, we discuss not only the material context of resource stocks and allocation patterns, but also the institutional context that decisively influences resource use. Based on these observations, we devise a set of water reform scenarios and simulate the effects of these with a dynamic CGE model of the Chinese economy. The results of these simulations provide evidence about the scope for policy reform to achieve sustained high growth in both rural and urban China.

## **Water Use and Impacts Due Ethanol Production in Brazil**

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Ethanol production from sugar cane crops uses significant amount of water in the agricultural and industrial processing phases. Most of the sugar cane plantations in Brazil rely on natural irrigation complemented by partial ferti-irrigation, carried out mainly to manage water wastes, limiting their production to regions where reasonable rainfall index occurs. Sugar cane processing to ethanol uses water collected mainly from surface water flows and, in few cases, from underground natural reservoirs for many different activities and it become contaminated with organic and inorganic pollutants.

Water availability is not a problem now or in the mid-term in a water rich country like Brazil, except in some specific regions where the amount of rainfall is not the most recommendable for sugar cane growth. Nevertheless, due the increasing demand for ethanol and the high prices paid for it sugar cane crops tend to expand to regions where natural irrigation needs to be complemented with artificial water spray. On the other hand water pollution caused by application of fertilizers and agrochemicals, by soil erosion, by cane washing, by fermentation, by distillation, by the energy producing units installed in the mills and by other minor sources of waste water is a major concern due the large size of such agro-industrial activity. The paper describes agricultural and industrial activities involved in ethanol production trying to quantify the amount of potential pollutants that are sources of water contamination and provides description of measures commonly used to mitigate such contamination and the ones used to clean waste water. Waste water quality returned to soil and to surface water flows is regulated by the government and such regulations are properly described and discussed. Suggestions on how to improve the quality of waste water above the present level imposed by regulation are also discussed. In particular, the main source of water pollution, stillage, is examined in detail as potential source of energy and other products while its intensity of contamination is reduced.

## **Biofuels : A strategy for enhanced water use efficiency, improved livelihoods and protecting environment in the SAT**

SP Wani, TK Sreedevi, AVR Kesava Rao and Yin Dixin

In dryland areas, water is the primary limiting factor in enhancing the productivity. As estimated, by 2025, 1/3 of the developing world largely in the SAT areas will be facing physical scarcity of water. Under such circumstances, competition for water to produce food, feed and fuel along with other uses becomes intense. Growing interests in biofuels, largely due to the concerns for the environment as well as the increasing oil prices, have attracted attention of many researchers and development investors. At ICRISAT, we are studying possibilities of alternative sources of energy such as biodiesel, biogas and bio-ethanol for increasing energy supplies using low water requiring crops. For biodiesel, *Jatropha*, *Pongamia*, and Neem which are dryland non-edible oil crops are studied for genetic variability as well as management practices for enhancing oil yields. The variability for seed size, seed weight and oil content is large in *Jatropha* as well as *Pongamia*. In *Jatropha*, oil content varies from 27-38% and in case of *Pongamia pinnata*, oil content varies from 27-39%. Results from the village-based model for extracting oil from *Pongamia* to generate electricity as well as to operate water pumps in tribal village are discussed. To rehabilitate degraded lands and common property resources, biodiesel plantations with *Jatropha curcas*, *Pongamia pinnata* and *Azadirachta indica* are used. We have developed a model on 300 ha in common property resources in two villages of Andhra Pradesh using mixed plantations of non-edible oil trees. The results of development model, germplasm variability, development of suitable agricultural practices and its use are discussed. In Asia, different feed stocks varying from pig manure, human excreta, *Jatropha* and sorghum seed are used for producing biogas which is used for cooking and electrification. Water use (evapotranspiration) by *Jatropha* varied from 20-140 mm per month depending on water availability and temperatures. During the first year of growth, maximum water extraction was observed from top 75 cm of soil. Results from various on-station and on-farm experiments are discussed in the paper.

## **Sweet sorghum: A Water Saving Bio-Energy Crop**

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Bio-fuels (bio-ethanol and bio-diesel) produced from renewable energy sources are gaining importance in the light of rising fossil fuel prices, depleting oils reserves and increasing 'green house effect' associated with the use of fossil fuels. Several developing and developed countries have made a mix of policies to promote the production and use of bio-fuels. Ethanol accounts for 90% of total bio-fuels production and use in the world at present. The major feedstocks currently used for ethanol production are sugarcane molasses in Asia and Africa, sugarcane juice in Brazil, and corn in the USA. Ethanol production from these feed stocks suffers from two major problems – increased water use (sugarcane and corn), and pollution (all three feedstocks) compared to sweet sorghum. Sweet sorghum is well adapted to the Semi-Arid Tropics (SAT) and more water-use efficient (310 kg water/kg dry matter) compared to maize (370 kg water/kg dry matter) to convert atmospheric CO<sub>2</sub> into sugars which makes it the most promising bio-energy crop. The food, feed and fodder needs of smallholder farmers will not be affected as the juice extracted from sweet sorghum stalks is used in ethanol production, The stillage leftover after the extraction of juice is an excellent dry matter source for livestock as it is rich in macro and micronutrients. Sweet sorghum has many advantages like seed propagation, short duration, suitability for mechanized crop production, and nearly three folds higher ethanol production capacity compared to sugarcane on the basis of water requirement and cheaper cost of ethanol production compared to sugarcane molasses which makes it an attractive alternative raw material.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India has identified/developed several varieties and hybrid parents with high stalk sugar content, biomass and juice yields in different maturity backgrounds. Research at ICRISAT showed that hybrids, besides being early are relatively less photoperiod and thermo sensitive than the varieties. The photoperiod and thermo insensitivity is necessary to facilitate scheduling the supply of sweet sorghum stalks depending on the needs of the industry. Per day ethanol productivity of some of the promising sweet sorghum hybrids (17.0 to 18.5 liter ha<sup>-1</sup>) developed at ICRISAT is far greater than those of check variety (SSV 84, 10.5 liter ha<sup>-1</sup>) and hybrid (NSSH 104, 10.7 liter ha<sup>-1</sup>) released for commercial cultivation in India. Development of sweet sorghum hybrids should receive high priority to produce more feedstocks per drop of water and unit of energy invested to supplement the current molasses, sugarcane and corn based ethanol production technologies to meet the future needs.

## **The Sustainability of Water Subsidies**

David Zilberman (UC Berkeley)

Throughout the world, in developing countries, water is subsidized. The rationales are many: water is essential for life, it belongs to the people, its availability is a natural right, etc. This reality reflects an historical evolution. In the past, water was not scarce. In many cases, water systems were designed to provide incentives for investment in water appropriation and diversion, and therefore, water was given freely or very cheaply. Later on, cheap access to water or energy for pumping was used to induce adoption of new technologies. As population has grown and water has become increasingly scarce, we encounter a reality that water has a price, and we have to move from systems of water rights and water subsidies to systems of water trading and payment of the real price of water.

The need to transition to real pricing is becoming increasingly crucial as the price of energy rises. If the price of energy triples, as happened in many parts of the world in the last five years, then the suddenly the budget allocated to subsidization of water prices cannot be sustained. Furthermore, with the introduction of biofuels, there is even greater demand for water for irrigation – which provides an additional source of budgetary pressure. Irrigation in many parts of the world is a major contributor to energy demand, and is a factor in raising its price. These are several synergetic elements that result in a situation that cannot be sustained.

This suggests a drastic change in water policy. Because water subsidies have a strong distributional element, some of the distributional benefits that the subsidy provides may have to be provided by other means. One possibility is to charge real prices for energy and water, but to subsidize conservation technologies. Another possibility is to develop a system of welfare payments, where incomes are subsidized but inputs are purchased at their real prices. A third approach is developing a system of tradable permits, where individuals have water rights they can buy and sell. What all of these systems have in common is providing incentives to reduce demand for water and to induce adoption of conservation technologies.

When it comes to conservation technologies, the recent rise in energy prices suggests that the conservation technologies that are most desirable are the ones that conserve both water and energy. These conservation technologies may be management intensive or may be high precision-low energy technologies (in terms of varying application of water to accommodate field conditions), but in many cases, they will be embodied in new varieties and crop management practices that reduce water use per unit of output. Technologies that reduce pest damage, increase yield or reduce loss in storage are all, to some extent, water -conserving technologies. Furthermore, increased productivity of rain-fed agriculture may reduce the pressure on irrigated agriculture.

The reduction and eventual elimination of water subsidies may lead to changes in farming that are not directly associated with water use, but are instead increasing substantially the productivity per unit of water and, under current conditions, per unit of energy.

# **Energy Price and Global Groundwater Extraction for Agriculture: Exploring Energy-Water-Food Nexus**

CLAUDIA RINGLER, Tingu Zhu and Joseph Green (IFPRI)

As oil prices have climbed to unprecedented heights the concern over sustainable energy use has intensified globally. Increased energy prices can have direct adverse impacts on some of the world's largest bread bowls like the Indo-Gangetic Plains, Northern China, and the western United States, due to their growing reliance on groundwater extraction for irrigation. This paper studies the effects of energy prices on global groundwater extraction with a global water and food model, IMPACT-WATER, through analyses of a set of alternative scenarios of energy price and water management policies.

Groundwater pumping, recharge, and simplified aquifer dynamics at the basin level are explicitly represented with a groundwater storage balance module within IMPACT-WATER. Groundwater use and water table changes under different scenarios are analyzed and the policy implications are derived regionally and globally.

## **A Comparative Assessment of Energy and Water Intensity of Potential Biofuel Crops in India**

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While it is reasonably clear that adoption of ethanol and biodiesel, can help reduce the dependence on crude oil, the evidence on the environmental benefits of such adoption like reductions in green house gas emissions, water and energy consumption for agricultural purposes and pesticide use etc. is far from conclusive. Previous research on biofuel crops has two major gaps. First, it has focused only on a handful of crops like corn, sugarcane, soy and canola. Second, it has largely been based on production in OECD countries (and to some extent production in Brazil). In this paper we look at two indicators, namely energy and water intensity (there are several others which are important too) of some non-conventional crops (i.e., crops either yet to be commercially adopted on a wide scale or unutilized as yet as biofuels) like *Jatropha Curcas*, *Pongamia Pinnata*, *Simarouba Glauca* and *Castor*. We also do a similar assessment for sugarcane based ethanol in India and compare it to sugarcane-based ethanol in Brazil. The main focus of this paper is on the agricultural phase of biofuels and not the entire life cycle from cultivation through end-use. Our approach is very straightforward involving a comparison of the requirements of major agricultural inputs like fertilizers, water etc. and yield of oil per hectare in order to determine the relative intensities of inputs for each type of energy crop. The crops analyzed here are especially suited to developing countries, in that they are considered to be non-intensive in inputs, suited to marginal lands and high yielding but have little history of commercial cultivation. It is hoped the analysis performed in this paper will bring to the fore the some merits and de-merits of types of energy crops, which have hitherto remained outside the focus of researchers and policy makers.

## **Irrigation Impacts of Diesel Price Increases on Marginal Farmers and Landless Laborers in India**

Tushaar Shah

Groundwater irrigation in India is facing a deep duality between electric and diesel pumps. Electric pump owners throughout India are enjoying the benefit of subsidy; in contrast, diesel pump owners have faced rapid and successive increases in fuel prices. Diesel pumps are concentrated in the poorest parts of India: eastern states and tribal regions of Jharkhand, Chhattisgarh, Madhya Pradesh, Vidarbha. These also happen to be the regions where groundwater is underutilized and pump irrigation is socio-ecologically most suited for small-holder agriculture. In western and southern India, in contrast, electricity subsidies intensify the already dire crisis of groundwater depletion. In rural India, owners of electric or diesel pumps and wells are often medium or large farmers. These commonly sell pump irrigation service to their neighbors who are too poor to own pumps and wells. These 'pump irrigation service markets' or pump rental markets have powerful impact on the village economy as well as on the fortunes of marginal farmers and the landless. Energy pricing has profound impact on the functioning of these markets and the price at which irrigation is made available by pump owners to marginal farmers

## **Micro-irrigation and electricity consumption linkages in Indian agriculture: a field based study**

A. Narayanamoorthy

Drip method of irrigation (DMI) introduced to improve the water-use efficiency has been practiced in different parts in India since early eighties. Quite a few studies have analysed the impact of drip method of irrigation on water use efficiency, water saving, cost of cultivation, labour use, productivity of crops, etc. using both experimental and farm level survey data in India. However, studies have not analysed the linkages between the adoption of DMI and electricity use in different crops using farm level survey data in Indian agriculture. DMI reduces the working hours of pumpsets through water saving and therefore, it reduces the consumption of electricity and also increases the efficiency of electricity use substantially. An attempt is made in this study to find out the linkages between the adoption of DMI and electricity use on three water-intensive crops namely banana, grapes and sugarcane, using farm level survey data collected from 200 farmers selected from Maharashtra, a western State of India. The study shows that farmers cultivating crops under DMI could save about 29 to 44 percent of electricity over the farmers who have cultivated the crops under flood method of irrigation. Electricity saving in terms of money value is estimated to be in the range of Rs. 3400-7900/ha in three crops selected for analysis.

## **Two faces of energy irrigation nexus in West Bengal, India: High flat rate electricity tariff and escalating diesel prices**

Aditi Mukherji (IWMI)

West Bengal, an eastern state of India is well endowed with groundwater resources, the total groundwater availability being 31 billion cubic meters. Yet farmers in West Bengal pay the highest electricity tariffs in the country. The state also has the rather dismal distinction of having the lowest number of electrified water extraction mechanisms (WEMs) anywhere in India. Only 12.2% of all WEMs in West Bengal are electrified, while this figure is almost 50% for India as a whole. All these three facts, viz. abundance of groundwater, high electricity tariff and low rates of pump electrification puts West Bengal in sharp contrast with most other Indian states such as Gujarat, Tamil Nadu, Andhra Pradesh, Punjab, Haryana etc. This has wide spread implications for groundwater management and food security.

First, abundant supply of groundwater and relative ease with which groundwater can be extracted has given rise to the ingenious institution of groundwater based informal pump rental markets. Based on primary data collected from 294 pump owners and 286 water buyers across 40 villages in West Bengal, this paper shows that informal pump rental markets have played a positive role in distributing benefits of irrigation to non-owners of WEM – who most often happen to be small and marginal farmers. Steep increase in flat rate electricity tariff over a brief span of a decade has provided suitable incentive to the owners of WEM to sell water in a pro-active manner, thereby benefiting multitudes of water buyers who otherwise would have remained outside the ambit of irrigated agriculture. Findings from this paper also shows that terms of water selling contracts have become more favorable towards the water buyers than they were a decade or so ago. I call this one face of the energy irrigation nexus.

The other face of the energy irrigation nexus is manifested in terms of rising diesel costs and its implications of agriculture. As already mentioned, almost 90% of all WEMs in West Bengal are diesel operated. The most important as well as profitable crop in the state is summer paddy (called *boro* paddy). *Boro* paddy is a highly water intensive crop requiring anything from 100-120 hours of irrigation per acre. It was the rapid increase in area and yields of *boro* paddy that led to high growth in West Bengal's agriculture. However, given the high diesel prices, cultivation of *boro* paddy has been rendered uneconomical. Hardest hit have been water buyers who can no longer afford to buy water for *boro* paddy cultivation from diesel WEM owners. There have been at least two major responses to increasing diesel costs. First there has been a shift in cropping pattern away from *boro* paddy to rain fed *rabi* crops in interior villages or vegetable and fruit cultivation in villages located near towns and cities. Second, conventional diesel pumps have been replaced with fuel efficient Chinese and Honda pumps.

The present paper, using primary data from 40 villages in West Bengal will capture the 'two-faces' of the energy irrigation nexus and will discuss its implications for policy and action.

## **Energy and Water Market in Bhavani Basin, Tamil Nadu, India**

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In terms of water sources, India is endowed with vast water and land resources. The geographical area of India is about 329 million hectare (m.ha) with a wide range of physiographical and climatic variations. India is among the foremost countries in the world in exploiting its river water resource. The increasing demand over supply of water, the worked out supply-demand gap based on the growth rates of irrigated crops is 2.12 m.ha.m (44.72 per cent). At the same time, the water demand for industries and municipal purposes are also increasing every day. The domestic and industrial uses of water at present claim a share about 15 per cent in the total resources and this share is likely to be about 25 per cent in the year 2025 AD with increased industrialization, urbanization and growing needs of rural areas for improved facilities for drinking water. Therefore, the rapidly growing urban and industrial water demands will need to be met increasingly from water transfers out of irrigated agriculture. This inter-sectoral transfer of water is now one of the major water issues in Bhavani Basin, Tamil Nadu particularly near the tail region of the canal system. Large numbers of farmers, who have their land along with and also away from the Bhavani river course are engaged in lifting water from the river and sell it to domestic and industrial purposes due to heavy demand coupled with favorable government policies with respect to electricity as free of cost and other related market forces induced farmers to intensify well market as a result of free electricity, demand for groundwater spiraled. The number of tanker trips on a given day depends upon the price of water as well as demand. Farmers sold water for Rs.15 per 1000 liters and Rs. 200 per tanker (13500 liters), and tankers would sell it for about Rs.60 per 1000 liters and Rs 800 per load. Increasing groundwater market has led to commercialization of water market instead of agriculture and has altered the cropping pattern and livelihoods of the basin farmers.

## **Water Quality and Environmental Dimensions in Biofuel Production**

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Human uses of freshwater resources and energy demand are increasing rapidly as the world population rises. Alternative energy using biomass feedstocks to reduce dependence on oil imports would entail conversion of million of hectares of farmland to produce profitable energy crops. There is a risk that profitable biofuel crop production will increase at the reduction of human food production which underpins the mandate of the Food and Agriculture Organization in achieving food security for all. In addition, the water needs of food and agriculture and its associated biofuel and bioenergy production have to consider the potential benefits and risks in regional scale environmental impacts and resource allocation and conservation needs. The specific environmental consequences due to land use changes not only relate to water quantity but quality from the standpoint of erosion, evapotranspiration, fertilizer and nitrate runoffs, and pesticide and agrochemical applications – which are generally not different from other farm crops. However, in recent years, alternative energy sources from short-rotation woody crops and herbaceous crops (perennial grasses) have been increasingly receiving interest in providing environmental and economic benefits to improve and utilize marginal lands, in serving as biomass crops in buffer strips to protect watersheds from agricultural runoffs, in providing habitat for local species, in sequestering carbon as well as in meeting human need for food, fibre and fuel. Thus, affecting the very resources farmers' rely for economic productivity and profitability. This paper will present the current literature on renewable biomass energy and in understanding favourable applications of biofuel production in preventing water quality deterioration and maintenance of biodiversity and ecosystem functions.

# **Agricultural Demand for Groundwater in Mexico: Impact of decoupling the subsidy for electricity user fees**

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The demand for agricultural groundwater is estimated through the natural experiment of having some aquifers more exploited than others, i.e., the price varies among aquifers due to the cost of pumping groundwater, which increases as the wells go deeper. This cost is summarized by the electricity bills that charge a fee for pumping groundwater for agricultural purposes.

The elasticity in absolute terms is greater when allowing for crop rotation or technological choice, which resembles a situation of medium to long run. The most restricted model derives a price elasticity of -0.15. Eliminating the fee subsidy implies a considerable lower pressure on the aquifers. In addition an analysis of decoupling the subsidy is done, whereby an income transfer is given while keeping the increase in the price of electricity. Decoupling results in increasing efficiency and sustainability while minimizing the negative distributional effects of eliminating the fee subsidy.

# **Pumping for conjunctive use and recirculation in an protective irrigation system and implications for equity, productivity, management and policy – the case of the Ghataprabha Left Bank Canal, Karnataka**

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The Ghataprabha Left Bank Canal, managed by the Karnataka Water Resources Corporation (KNNL), has been appraised in 2006, with assistance from FAO, with a Rapid Appraisal Procedure, following which a plan for improvement of management has been prepared following FAO's MASSCOTE methodology.

Officially described and operated as a protective surface irrigation system irrigating staple crops, the system is in fact a highly productive commercial system dominated by sugarcane and other cash crops, thanks to extensive pumping of groundwater, most of which is recharged and pumped drainage recirculation. As a result, water productivity and income per hectare are 5 times higher than estimated for the official cropping pattern. As energy for pumping (which is valued at 0.60 rup./m<sup>3</sup>) is entirely subsidized, farmers refuse to pay the nominal service fee for the (poor) canal water delivery service, which it costs 0.10 rup./ha for KNNL to provide. The State finances both canal water and energy consumption.

The paper presents detailed results of the system's water balance, energy consumption and performance appraisal and discusses major implication in terms of redefinition of hydraulic equity, accepting the need for flexible cropping patterns, shifting from protective to productive irrigation, service oriented management and explicit integrated management of all sources and uses of water, and revisiting the concepts and practices of "payment for water services" linking water and energy consumption in the present situation.

## **The Effects of Energy Costs on Water Allocation in a Basin**

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This paper will examine how the cost of water transportation and pumping may affect allocation of water in a river basin. In particular, the substitution between ground and surface water resources. We develop a spatial model of water allocation and examine the solution when the cost of water transmission is higher. What is the effect of energy costs on the allocation of production, the adoption of water conservation technologies as well as the use of ground and surface water resources by firms? How will the organization of production change with a rise in the cost of energy? The paper will extend existing models of water allocation that treat energy costs as constant.