Figure 6.1 Water productivity 'gap.' Source: Sadras and Angus, 2006.

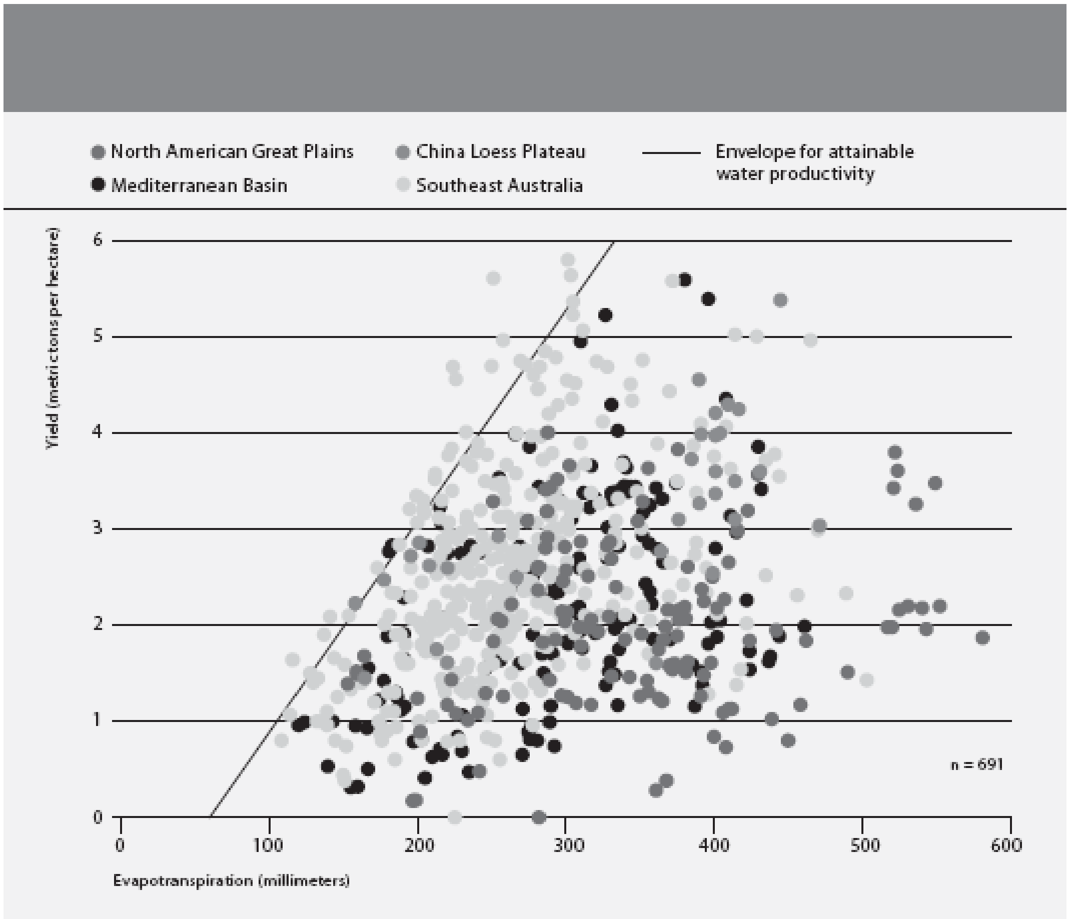


Figure 6.2 Water productivity rises faster at lower yields and levels off at higher yields. Source: Adapted from Zwart and Bastiaanssen, 2004.

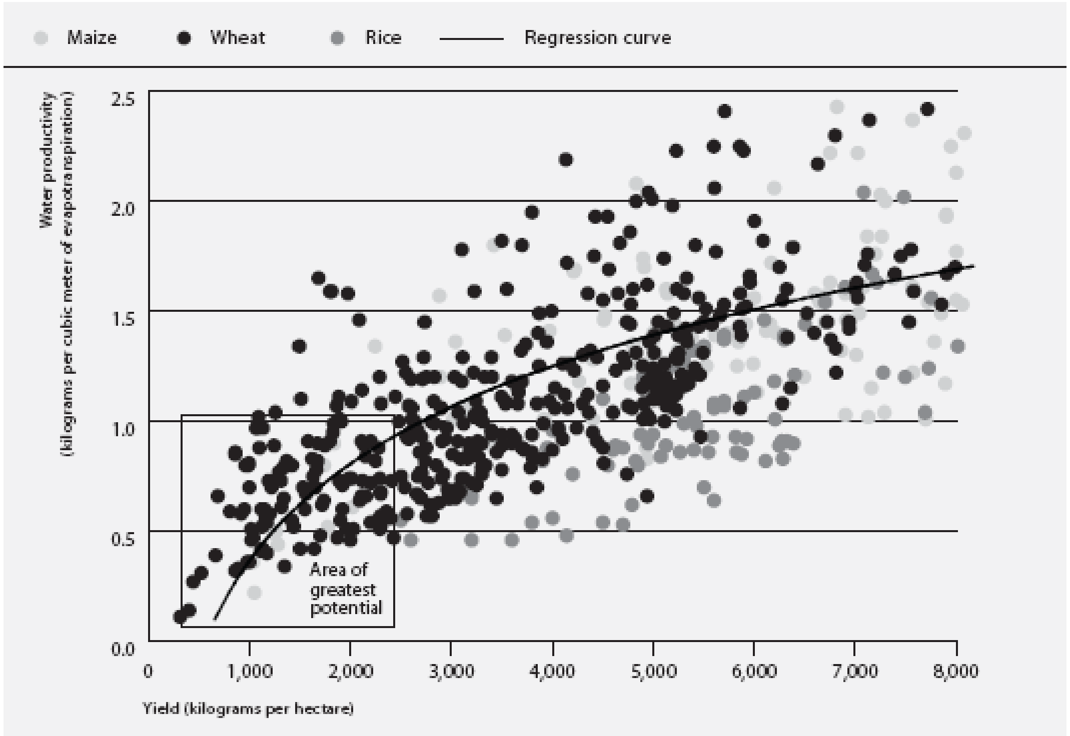


Figure 6.3 Sequential reuse of drainage water on drainage affected lands as proposed in the San Joaquin Valley drainage Implementation Programme, California. Source Qadir et al., 2007.

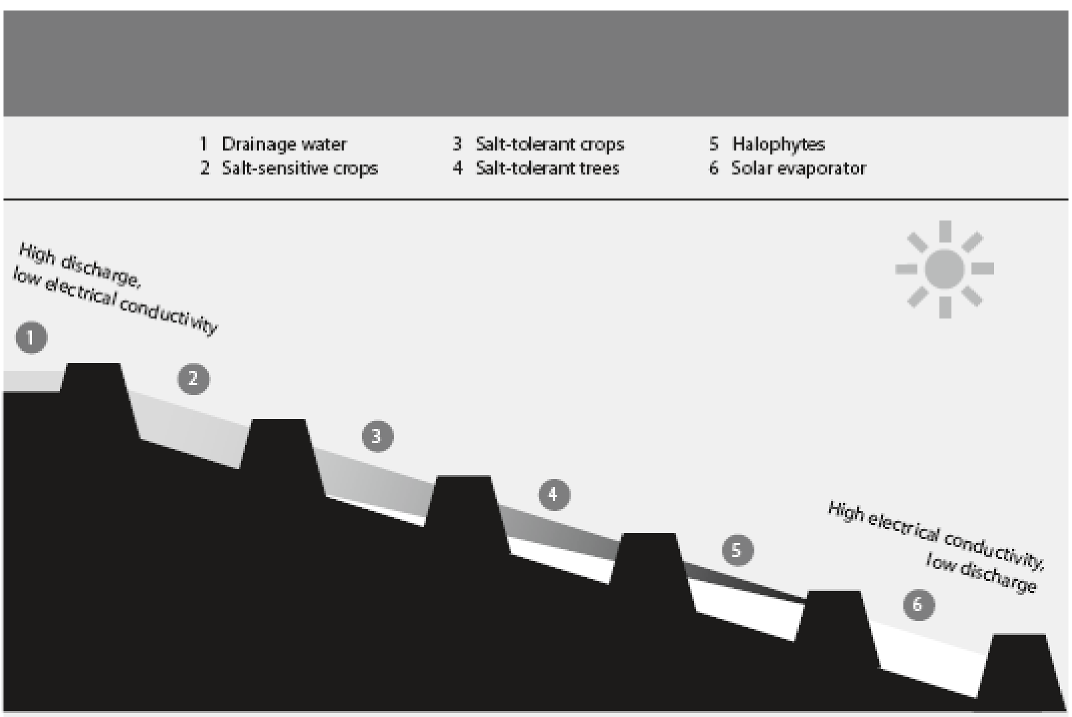
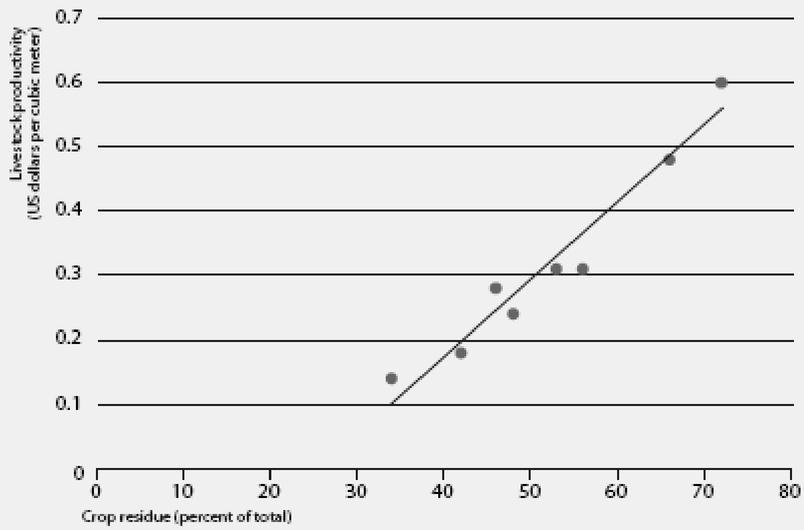


Figure 6.4 Livestock water productivity is positively correlated with the share of animal diets composed of crop residues and by-products in Ethiopia's Awash River Valley. Source: Peden et al., 2007.



Note: This example takes into account livestock's multiple values in terms of providing milk, meat, and farm power. Evapotranspiration enabling grain production also results in valuable stover for use as animal feed without using more water.

Table 6.1 Key relationships between future challenges and agricultural knowledge, science and technology options for action.

Key relationships between future challenges and agricultural knowledge, science and technology (AKST) options for action

Challenges \ AKST options for action	Water management	Resource management	Conservation agriculture	Breeding and biotechnology	Public participation	Soil conservation	Pestpathogen management	ICT and Diagnostic technologies	Local uses of bioenergy	GIS and Remote Sensing	2nd generation biofuels
Maintaining yield in high productivity systems	■	■	■	■		■	■	■		■	
Adapting to climate variability and change	■	■	■	■	□	■	■	□	□	□	□
Closing yield gaps in low productivity systems	■	■	■	■	■	■	■	□			
Preserving natural resources, biodiversity and ecosystems	■	■	■	■	■	□	□		□	■	□
Enhancing health and nutrition	■	■	□	■	■		■	■			
Managing water scarcity	■	■	■	■	□	■		□		□	
Diversifying agricultural systems	■	■	□		□	□	■		□		□
Sustainable use of bioenergy	■	□		□	□	□			■		■
Linking knowledge systems	□		□		■	□	□		■		

■ Very important for addressing this challenge

□ Option contributes to addressing this challenge

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Table 6.2 AKST options for addressing main challenges with related AKST gaps and needs.
Key: A = AKST exists, B = AKST emerging, C = AKST gaps

AKST Potential to Address Challenge	AKST Gaps and Needs: Technology and knowledge	AKST Gaps and Needs: Capacity Building, Policies, and Investments	Regional applicability
Preserving and maintaining natural resources and ecosystems			
Minimize the negative impacts of agriculture expansion on ecosystem services (6.3.1.1, 6.1.1.1).	Trade-offs analysis to assess dynamic relations between the provision of ecosystem and economic services in conflicting areas. Develop biotechnologies to reduce impacts	Training of researchers, technicians, land administrators and policy makers for the application of trade-offs analytical tools, and adoption of improved crop plants.	LAC (B)
Design of multi-functional agricultural landscapes that preserve and strength a sustainable flow of ecosystem services (6.7.5.2).	Configure systems to resemble structural and functional attributes of natural ecosystems	Enhance local capacities to develop land use strategies and policies to maximize the supply of essential ecosystem services.	LAC, SSA, tropical Asia (B)
Enhance the geographical spread of multi-functional agricultural systems and landscapes (6.7.5.2.1).	Typify the ecological-service supplier as a new category of rural producer.	Implementation of public recognition and payment systems for ecological service suppliers that provide demonstrable services to society.	All regions
Creation of more conservation management areas (6.3.1.1)	Research designed to optimize productivity of the small/subsistence farmer. Incentives for in situ conservation	Promote transboundary initiatives and legislation	All regions
Sustainable management of fisheries and aquaculture (6.5)	Improved knowledge of contributions of capture and cultured fisheries to food and nutrition, food security and livelihoods	Promote alternative strategy for meeting the increasing demands for fish products Promote genetically improved fish technology	All regions
Environmental management of dams to reduce impact on aquatic ecosystems (6.6.3)	Environmentally sound management of dams		All regions
Basin water management (6.6.3.2)	Basin management tools Benefit sharing tools for negotiation	Policies for effective water allocation	All regions
Improving water management			
Improve water productivity by reducing evaporative losses (6.6.3.1)	Biotechnologies including genetics and physiology B,C		Semi-arid areas (A)
Restore existing irrigation systems (6.6.3.1)	Environmentally sound management of irrigation systems	Investment in irrigation	S and SE Asia, Central Asia, China (A); SSA (B)
Increase sustainable use of groundwater (6.6.3.2)	Hydrologic process understanding for sustainable use of groundwater		S. Asia, China (A) SSA (B)
Precision irrigation, deficit irrigation (6.6.3.1)	Technologies for use of low quality water in precision irrigation	Policies for secure access to water and for effective water allocation	NAE, MENA (A) S&SEAsia,SSA (B)
Rain water harvesting, supplemental and small scale	Affordable small scale technologies for rain water	Investment in water management for rainfed	S.Asia, SSA (A)

AKST Potential to Address Challenge	AKST Gaps and Needs: Technology and knowledge	AKST Gaps and Needs: Capacity Building, Policies, and Investments	Regional applicability
irrigation for rainfed agriculture (6.6.3.1; 6.5.1.3)	harvesting and water management	systems	
Integrated soil water and soil fertility management (6.4.2.1)			S. Asia, SSA (A)
Multiple water use systems, domestic and productive uses, crops/livestock/fisheries (6.4.2.2)	Institutional and design requirements for MUS systems	Policy that promotes sector integration	All regions
Basin water management (6.4.2.2)	Basin management tools Benefit sharing tools for negotiation	Policies for effective water allocation	All regions
Linking knowledge systems			
Promote local uses of biodiversity (6.1.2; 6.8.1.2)	Mobilize and promote indigenous technologies and innovation systems, and resolve intellectual property issues.	Education, training and dissemination, extension; international coordination of IPR systems.	All regions
Enhance participatory approaches for natural resource management (6.7.5.1)	Merge farmer-based and region-specific innovation systems with formal research Improved collaborative NRM for rare species (CITES) Formal and indigenous mapping tools for monitoring of fragmented biodiversity	Gender mainstreaming Scientific and digital divide Education, training and extension, equity, transboundary initiatives and collaborations	All regions
Increase participatory research that merges indigenous and Western science (farmer field schools, seed fairs) (6.6.1; 6.7.5.1)	Develop affordable technologies that integrate local, farmer-based innovation systems with formal research	Promotion of grassroot extension, transboundary collaborations	All regions
Promote underutilized crops (6.6.1; 6.5.1.7)	Develop approaches that integrate local knowledge systems with formal research	IPR, biopiracy, information and dissemination	All regions
Enhancing health and nutrition			
Detection, surveillance, and response to emerging diseases (6.7.3) Better surveillance of zoonotic diseases Early disease warning systems Integrated vector and pest management Environmental management of dams to reduce vectorborne disease	Improve understanding of disease transmission dynamics More rapid and accurate diagnostic tools Improved vaccines Develop faster genomic-based methods for diagnostics and surveillance	Public health infrastructure and health care systems Better integration of human and veterinary health	SSA, S. and SE Asia (B)
Biofortification of crop germplasm (6.2; 6.7.1; 6.7.2)	Cost effective and efficient screening methods for breeding and introducing multi-gene traits Incorporate multiple nutrient traits	Public sector financing and work force Biosafety protocol Public sector investment	SSA, S. and SE Asia (A,B)
Multiple water use systems, domestic and productive uses, crops/livestock/fisheries (6.6.3)	Institutional and design requirements for MUS systems, such as Rice+Fish program; rice livestock programs	Policy that promotes sector integration; Enhance incentives for breeders	All regions

AKST Potential to Address Challenge	AKST Gaps and Needs: Technology and knowledge	AKST Gaps and Needs: Capacity Building, Policies, and Investments	Regional applicability
Closing yield gaps in low productivity systems			
Improve practices for root health management (6.1.3)	Genomics-based diagnostic tools for understanding root disease dynamics	Bolster S&T capacity in pest management	All regions
Conventional Breeding/rDNA assisted (6.3.1.1; 6.8.1.1)	Incorprate traits that confer stable performance like weed competitiveness, resistance to pest & diseases & tolerance to abiotic stresses	IPTGR Plant Variety Protection Public sector investment	All regions (A, B)
Transgenics (GM) (6.3.1.2)	Develop biosafety testing methodologies. Incorporate genes conferring stable performance	Biosafety protocol Public sector investment	All regions (A, B)
Improve the performance of livestock in pastoral and semi-pastoral subsistence communities. (6.2.1)	Enhance nutrient cycling	Improve access to grazing and water-endowed areas for nomadic and semi-nomadic communities	SSA (A, B)
Rain water harvesting, supplemental and small scale irrigation for rainfed systems (6.8.1.2)	Affordable small scale technologies for rain water harvesting and water management	Investment in water management for rainfed systems	SAsia, SSA (A)
Integrate soil water and soil fertility management (6.6.2.2; 6.6.3.3)	Enhance crop residue return to bolster soil organic matter levels, seed treatment of fertilizer with improved rainwater capture		SAsia, SSA (A)
Multiple water use systems, domestic and productive uses, crops/livestock/fisheries (6.6.3.2)	Institutional and design requirements for MUS systems	Policy that promotes sector integration	All regions
Maintaining yields in high productivity systems			
Conventional Breeding/rDNA assisted (6.3.1.1)	Develop varieties with higher yield potential	IPTGR; Plant Variety Protection Re-invest in plant breeding professionals	All regions
Transgenics (GM) (6.3.1.2)	Incorporate yield enhancing traits Appropriateness to small holder systems	Biosafety protocol; Public sector investment IPR issues to resolve	All regions
Soil nutrient management to reduce pollution (6.6.2.1)	Wider adoption of precision agriculture technologies	Regulations and law enforcement in developing countries	All regions
Improve performance in intensive livestock systems (6.2)	Application of production methods and techniques to optimize the use of inputs.		All regions with livestock systems
Enhance livestock productivity through use of biotechnology, genomics and transgenics for breeding 6.3.2)	Enhance capacities for gene identification and mapping, gene cloning, DNA sequencing, gene expression.		All regions
Restore existing irrigation systems (6.6.3.1)	Environmentally sound management of irrigation systems	Investment in irrigation	SE Asia, S. Asia, Central Asia, China (A); SSA (B)

AKST Potential to Address Challenge	AKST Gaps and Needs: Technology and knowledge	AKST Gaps and Needs: Capacity Building, Policies, and Investments	Regional applicability
Increase sustainable use of groundwater (6.6.3.2)	Hydrologic process understanding for sustainable use of groundwater		S. Asia, China (A) SSA (B)
Improve sustainability of protected cultivation (6.1.1.1)	Low-cost multi-functional films Ecologically sound management for greenhouses	Internalize externalities	NAE, Mediterranean (A) LAC, SSA (B)
Precision irrigation, deficit irrigation (6.6.3.1)	Technologies for use of low quality water in precision irrigation	Policies for secure access to water and for effective water allocation	NAE, MENA (A) S. and SE Asia, SSA (B)
Adaptation to and mitigation of climate change			
Broader adoption of soil conserving practices to reduced projected increase in soil erosion with climate change (6.8.1.1)	Prioritization of soil erosion 'hotspots'	Enhance land tenure security Strengthen conservation allotment policies.	All regions, esp. in mountainous develop. countries
Conventional breeding and biotechnology to enhance abiotic stress tolerance (6.3.1.1; 6.2; 6.8.1.1) Genetic and agronomic improvement of underutilized crops (6.8.1.1)	Change crop types; agroecosystem zone matching; Identify genes needed for GM	Biosafety protocol Public sector investment	All regions
Increase water productivity to bridge dry spells (6.8.1.2) Small-scale development of drip irrigation, treadle pumps (6.6.3.3)	Broader promotion of supplemental irrigation, soil nutrient management, improved crop establishment practices.	Policies for secure access to water Investment in risk reduction strategies	SSA, S. Asia, MENA (A)
Storage: rain water harvesting, small scale, large scale (6.6.3; 6.8.1.2)	Environmentally sound construction and management of large dams Decision support for scale of storage that is environmentally and socially sound	Enhance land tenure security Water rights and access	SSA, S. Asia (A)
Reduce agricultural GHG emissions (6.8.1.1)	Aerobic rice production (CH_4 and N_2O) Site specific nutrient management (N_2O) Animal feed improvement (CH_4 and N_2O) Expand land-based C sequestration potential	Transitional costs associated with land management changes Capacity building for outreach and extension	All regions
Sustainable use of bioenergy			
Production and use bioenergy to promote rural development (6.8.2)	Promote R&D for small-scale biodiesel and unrefined bio-oils for local use to improve energy access in local communities	Capacity building, promote access to finance	SSA, S. and SE Asia, LAC
	Promote R&D to reduce costs and improve operational stability of biogas (digesters), producer gas systems and co-generation applications	Develop demonstration projects, product standards and disseminate knowledge	All regions
Improvements in the environmental and economic	Promote R&D for 2nd generation biofuels focusing on	Facilitate the involvement of small-scale	High-income

AKST Potential to Address Challenge	AKST Gaps and Needs: Technology and knowledge	AKST Gaps and Needs: Capacity Building, Policies, and Investments	Regional applicability
sustainability of liquid biofuels for transport (6.8.2.1)	reducing costs to make them competitive. Conduct research on environmental effects of different production pathways.	farmers in 2nd generation biofuels/feedstock production and low-income countries, e.g. by developing smallholder schemes, improving access to information and dealing with IPR	regions (B) Low-income regions (C)

Table 6.3 Summary of changes in water productivity (WP) by major crop type arising from adoption of sustainable agricultural technologies and practices in 144 projects (adapted from Pretty et al., 2006).

Crops	WP before intervention (kg food m^{-3} water ETa)	WP after intervention (kg food m^{-3} water ETa)	WP gain (kg food m^{-3} water ETa)	% Increase in WP
Irrigated				
Rice (n=18)	1.03 (±0.52)	1.19 (±0.49)	0.16 (±0.16)	15.5%
Cotton (n=8)	0.17 (±0.10)	0.22 (±0.13)	0.05 (±0.05)	29.4%
Rainfed				
Cereals (n=80)	0.47 (±0.51)	0.80 (±0.81)	0.33 (±0.45)	70.2%
Legumes (n=19)	0.43 (±0.29)	0.87 (±0.68)	0.44 (±0.47)	102.3%
Roots and Tubers (n=14)	2.79 (±2.72)	5.79 (±4.04)	3.00 (±2.43)	107.5%

Table 6.4 Current remote sensing technologies for global agroenvironmental health and resources monitoring and assessment for sustainable development.

Types of Remote Sensing	Sensor Description	Example of Imaging Sensors	Resolution	Limitations	Application in Agriculture	Other applications
1. Optical Imaging						
a. Panchromatic	Single channel detector sensitive to broad wavelength range produce black and white imagery	● IKONOS Pan	Spatial: 1 m Spectral: 1 band Temporal: 1 - 3 days	● Unlike microwave remote sensing, acquisition of cloud free image using optical bands is impossible because of its short wavelength that can not penetrate clouds and rain.	▪ Precision farming ▪ Property damage control and verification of crop damage, e.g. drought and hail.	▪ Highly detailed land use discrimination, urban mapping, natural resources and natural disasters mapping, environmental planning, land registration, public health, biodiversity conservation, coastal monitoring, homeland security.
		● SPOT Pan	Spatial: 10 m Spectral: 1 band Temporal: 1 - 26 days	Resolution trade off: High spatial resolution associated with low spectral resolution.	▪ Farm planning, precision farming	▪ Urban planning, feature and asset mapping, land use mapping
b. Multispectral	Multichannel detector with a few spectral bands. Sensitive to radiation with narrow wavelength band. The image contains	● Landsat MSS	Spatial: 50-80 m Spectral: 5 bands Temporal: 18 days		▪General vegetation inventories and classification	▪ Environmental monitoring, land use mapping and planning, forest mapping, statistical land-use survey global-change, urban area mapping, detection of silt-water flowing and landscape analysis.

		● Landast TM ● SPOT HRV-XS	Spatial: 25 m Spectral: 7 bands Temporal: 16 days Spatial: 20 m Spectral: 3 bands Temporal: 1-26 days		▪ Discrimination of vegetation types and vigor, plant and soil moisture measurement, Cropping pattern mapping, chlorophyll absorption, biomass survey, plant heat stress ▪Vegetation mapping and monitoring, soil erosion, agricultural boundary detection,	▪ Water penetration, differentiation of snow and ice landscape analysis, lineament detection, lithological classification, urban environment assessment, delineation of water bodies, hydrothermal mapping. Urban mapping, forestry mapping and planning, land use and land cover discrimination, maritime and coastal management, resource stewardship monitoring, habitat supply planning, wildfire mapping, land slide and mudflow detection, and rapid urban change.
c. Superspectral	Imaging sensor has many more spectral channels (typically >10) than a multispectral sensor. The bands have narrower bandwidths that capture finer	● IKONOS MS ● MODIS ● ENVISAT MERIS	Spatial: 4 m Spectral: 4 bands Temporal: 1-3 days Spatial: 250,500,1000 m Spectral: 36 bands Temporal: 1-2 days Spatial: 300, 1200 m Spectral: 15 bands	Multi, super and hyper spectral have resolution trade off: Sensors with high multispectral resolution can only offer low spatial resolution.	▪ Precision farming, vegetation mapping, disease detection ▪ Drought detection, vegetation monitoring and forecasting ▪ Inventory and yield estimation. ▪ Crop type mapping	▪ Environmental analysis, land management, urban growth mapping and updating, disaster mitigation and monitoring Highly detailed land use discrimination ▪ Atmospheric temperature measurement, ozone/cloud/atmospheric properties, ocean color, phytoplankton, biogeochemistry, land cover mapping, land use planning land cover characterization and change detection. ▪ Forest inventory and change detection. ▪ Evaluation of tropohospheric aerosol

			Temporal: 3 days		▪ Monitoring of seasonal land cover changes. ▪ Global vegetation monitoring	properties, hazard monitoring ▪ Measures sea surface temperature, color and surface roughness
d. Hyperspectral	It acquires images in about a 100 or more contiguous spectral bands. The precise spectral information enables better characterization and identification of targets.	● Hyperion	Spatial: 30 m Spectral: 220 bands Temporal: 16 days		▪ Precision farming, crop type mapping, monitoring of crop health, moisture and maturity.	▪ Coastal management (monitoring of phyto-planktons, pollution and bathymetry changes)
2. Microwave Imaging	Encompasses both active and passive remote sensing. It covers long wavelengths from 1cm-1m which can penetrate through cloud cover, haze, dust, and all but the heaviest rainfall all day and all weather imaging.			● Image distortions. Extensive shadowing of areas characterized with relief. ● Coarse resolution, especially for passive applications. ● Radar images are rather difficult to deal with. The few commercial software packages that exist to deal with radar imagery offer a limited amount of functions. ●Results are better when		
(widely used bands) a. C Band	8,000-4,000 MHz; (3.8-7.5 cm)	● RADAR SAT-SAR (5.6 cm)	Spatial: 8,25,30,50, 100m Spectral: C band Temporal: 24 days		▪ Crop monitoring and forecasting, crop mapping	▪ Flood detection, for disaster management, risk assessment, pollution control (oil spill), coastline mapping.

b. L Band	2,000-1,000 MHz; (15.0-30.0 cm)	● ALOS-PALSAR (1270 MHZ)	Spatial: 10-100 m Spectral: L band Temporal: 46 days		▪ Agricultural monitoring	▪ Distinction of forest from grassland, land cover classification volcanic activity monitoring, flood monitoring, landslide and earthquake detection, detection of oil slick, forest biomass estimation.
3. Light Detection and Ranging (LIDAR)	An active sensor that transmits laser pulses to the targets and records the time the pulse returned to the sensor receiver. Laser is able to provide light beam with high intensity, high collimation, high coherence, high spectral purity, and high polarization purity.	LIDAR (airborne)	Spatial: 0.75 m Spectral:1.045-1.065 µm Temporal: dependent on flight schedule	Disadvantages are low coverage area and high cost per unit area of ground coverage. It is not cost-effective to map a large area using an airborne remote sensing system.	▪ Crop monitoring, plant species detection, can be used for agricultural planning and crop estimation	▪ Forestry management, shoreline and beach volume changes lines, flood risk analysis, habitat mapping, subsidence issues, emergency response, urban development, and monitoring of environmental changes.

Table 6.5 Land area requirements for biofuels production. Source: Avato, 2006

Percentage of total 2005 global crude oil consumption to be replaced by bioenergy	**Energy Yield**			
	1^{st} generation biofuels		Next generation biofuels	
	40 GJ/ha	60 GJ/ha	250 GJ/ha	700 GJ/ha
5 % ~ 1500 million barrels/year	230 million ha	153 million ha	37 million ha	13 million ha
10% ~ 3010 million barrels/year	460 million ha	307 million ha	74 million ha	26 million ha
20% ~ 6020 million barrels/year	921 million ha	614 million ha	147 million ha	53 million ha

Conversion factors: 1 GJ=0.948 million BTU; 1 barrel of oil ~ 5.8 million BTU

Table 6.6 Bioenergy: Potential and Limitations

Technological Application	Potential Benefits	Risks and Limitations	Options for Action
1st Generation Biofuels	- Energy security - Income and employment creation - GHG emission reductions	- Limited economic competitiveness - Social concerns, (e.g. pressures on food prices) - Environmental concerns (e.g. depletion of water resource, deforestation) - GHG emission reductions strongly dependent on circumstances	- R&D on improving yields of feedstocks and fuel conversion - More research on social, environmental and economic costs and benefits - Policies/initiatives furthering social and environmental sustainability
Next Generation Biofuels	- Larger production potential and better GHG balance than 1st generation - Less competition with food production	- Unclear when technology will be commercially viable - High capital costs and IPR issues limit benefits for developing countries and small-scale farmers - Issues with over-harvesting of crop residues, GMOs	- Increase R&D to accelerate commercialization - Develop approaches to improve applicability in developing countries and for small-scale farmers
Bioelectricity and Bioheat (large-scale)	- Low GHG emissions - Favorable economics in certain off-grid applications (e.g. bagasse cogeneration)	- Issues with operational reliability and costs - Logistical challenges of feedstock availability	- Develop demonstration projects, product standards - Disseminate knowledge - Access to finance
Bioelectricity and Bioheat (small-scale)	- Potential for increasing energy access sustainably in off grid areas with low energy demand using locally available feedstocks	- Costs, operational reliability, maintenance requirements	- R&D on small-scale stationary uses of biodiesel and bio-oils - Capacity building on maintenance

Box 6.1 Advantages of the Mediterranean glasshouse system

The Mediterranean greenhouse agrosystem represents greenhouse production in mild winter climate areas and is characterized by low technological and energy inputs. Strong dependence of the greenhouse microclimate on external conditions (La Malfa and Leonardi, 2001) limits yield potential, product quality, and the timing of production. It keeps production costs low as compared to the Northern European greenhouse industry. The latter is based on sophisticated structures, with high technological inputs that require important investments, and produces higher yields at higher costs (Castilla et al. 2004).

Box 6.2 The importance of crop varietal diversification as a coping strategy to manage risk

A study of traditional practices of conserving varieties of yam, *Dioscorea* sp., and of rice, *Oryza glaberrima*, was carried out in Ghana in 2003-2004 under an IPGRI-GEF-UNEP project on crop landraces in selected sub-Saharan African countries (Gyasi et al. 2004). It identified 50 varieties of yam and 33 varieties of rice that are managed by a wide diversity of locally adapted traditional practices in the study sites located in the semi-arid savanna zone in the northern sector. The case study findings underscore the importance of crop varietal diversification as security against unpredictable rainfall, pest attack, fluctuating market and other such variable environmental and socio-economic conditions, not to mention its importance for modern plant breeding and wider use of farm resources, notably labor and the diversity of on-farm ecological niches.