Research priorities for agricultural drainage in developing countries

C L Abbott
P B Leeds-Harrison

TDR Project R6879

Report OD/TN92
February 1998

Cranfield UNIVERSITY

HR Wallingford

DFID Department For International Development

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Address and Registered Office: **HR Wallingford Ltd**. Howbery Park, Wallingford, OXON OX10 8BA
Tel: +44 (0) 1491 835381 Fax: +44 (0) 1491 832233

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Contract

This report on the needs for drainage research was carried out for the Department for International Development as the initial output of a research project, the details of which are included below:-

Theme	Improve availability of water for sustainable food production and rural development
Theme no.	W5
Project	Aids to improved agricultural drainage
Project no.	R6879

Note: For the purposes of this report the terms "drainage", "agricultural drainage", "artificial drainage" and "improved drainage" are synonymous.

Prepared by ......Catherine Abbott......

(name)

......Senior Scientist......

(Title)

Approved by ......[signature]......

(name)

......Head Overseas Development Unit......

(Title)

Date......16/3/98......

Summary

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Worldwide production from irrigated agriculture needs to rise by 3% per year until well into the next millennium to keep pace with rising populations (World Bank, 1993a).

However, 20-30 million ha of irrigated land are now seriously affected by problems of waterlogging and salinisation caused by poor water management and inadequate drainage. Smedema and Ochs (1997) estimate that the affected area is growing by about 5% each year.

The World Bank (WB, 1993b) identified inadequate or inappropriate drainage as the most severe long-term problem facing agricultural production. Without effective drainage, the benefits of irrigation are forfeit. Affected lands are characterised by one or more of the following constraints: reduced cultivated area, reduced yield, curtailed cropping seasons, limited choice of crops.

Many of the problems constraining drainage are social, economic or institutional in nature. Nonetheless, there are substantial technical issues directly affecting irrigation scheme performance and output, for which practical solutions remain to be developed. Some technologies have been successfully transferred from the developed to the developing world, but there is an urgent need to produce appropriate solutions, particularly for humid areas.

The purpose of the present document is to:

- identify important technical issues in drainage for which solutions are needed.
- direct available research resources to areas of priority need.
- promote the application of research output in the developing world through training and the development of appropriate management tools.

The International Program for Technology Research in Irrigation and Drainage (IPTRID) has identified national research needs in missions to major irrigating nations (Appendices 2 and 3). Some two thirds of all identified projects involve problems with drainage. This document draws upon world-wide experience to identify generic research needs.

Summary (continued)

Six priority areas for research, considered to be of primary importance to improving longterm agricultural output in the developing world, are identified. They are:

1. Integration of irrigation and drainage to improve productivity with reduced water use.
2. Quantification of drainage benefits and identification of optimum investment strategies.
3. Preventative and remedial measures to improve drainage performance.
4. Drainage and reclamation of problem soils.
5. Drainwater disposal, reuse and related issues.
6. Tools for planning and design of drainage.

The six research areas are discussed with particular attention to the nature and scale of the problem in each case, and a brief review of existing work. Priority research topics are highlighted in each area. The case is made that research must be capable of integrating the findings from individual projects and that drainage must be considered as part of a wider integrated water management system within a basin.

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1. INTRODUCTION

The role of drainage in sustainable agriculture

History has shown time and time again that without adequate drainage, agriculture is unsustainable. Agricultural production relies on land that is neither too wet nor too dry. In irrigated areas, irrigation supplies water to the crop rootzone, but without removal of surplus water and salts by drainage, waterlogging and salinisation lead to crop yield reduction and land degradation. In unirrigated humid agricultural areas, excess rainfall must be removed to prevent flooding and waterlogging.

The benefits of irrigation are well documented. Global estimates indicate that irrigated agriculture produces 40% of total food and agricultural commodities from 17% of agricultural land (HR Wallingford, 1997). Future food security is critically dependent on irrigated agriculture as global population growth rates require an increase in production of 40 to 50% over the next thirty to forty years (World Bank, 1993a).

Awareness of the importance of drainage to sustainable agriculture is growing. The World Bank (1993b) identified inadequate or inappropriate drainage as perhaps the most severe longterm problem reducing the benefits of irrigation and leading to noxious environmental effects.

Role of Drainage

Drainage is the mechanism by which excess water and solutes (eg salts) are removed from agricultural land. In some areas natural, drainage is adequate to prevent problems, but increasingly artificial or improved drainage is required to control waterlogging and salinisation of the rootzone, or to prevent surface flooding of land during periods of high rainfall.

Waterlogging and flooding hamper crop development and reduce output by:

- reducing root respiration and total root volume,
- increasing resistance to transport of water and nutrients,
- allowing toxic compounds to accumulate,
- cooling the soil, thus delaying and slowing crop development in cooler climates,
- restricting access for machinery so decreasing the length of the growing season.

Poor drainage results in:

- decreased cultivated area
- reduced crop yields
- limited choice of crops.

Drainage is widespread in the developed world, but not in developing countries. In Northwest Europe some 34% of farmland is drained, whereas only 4% of agricultural land in South East Asia is formally drained. In South West Asia 37% of cultivated land is irrigated, but only 9% is drained. Developing countries have invested heavily in irrigation but drainage has been largely neglected.. Although there are notable exceptions, investment in drainage in developing countries is mostly limited to main drains on government irrigation schemes and to commercial estates.

Worldwide, Smedema & Ochs (1997) estimate that to date drainage has been improved in only one third of the total area in which natural drainage constrains agricultural development. Figure 1 shows drained and irrigated land as a percentage of total cultivated land in different parts of the world.

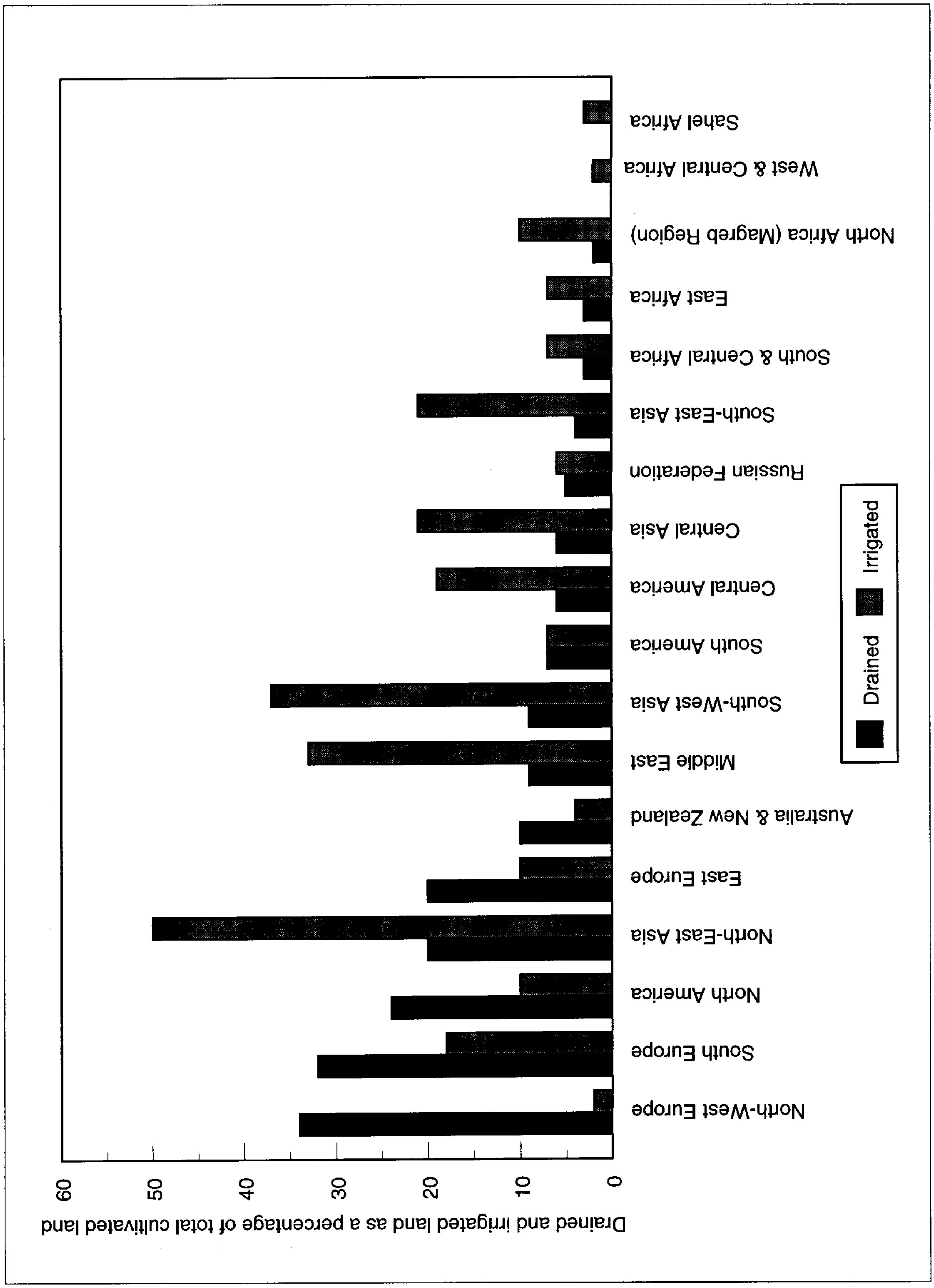

Figure 1 **Drained and irrigated land as a percentage of total cultivated land (adapted from Smedema and Ochs, 1997)**

Investment in drainage and drainage research has historically been low for a number of reasons including:

- Cost.
- Delayed recognition that poor drainage is an important constraint on yield once irrigation supply problems are resolved.
- The prevailing cropping system. (In humid areas, farmers have traditionally grown rice in rainfed conditions where it is important to conserve water on the plots, draining down at certain points in the cropping cycle only).
- The small size of farms. Drainage is a cooperative exercise which, in such circumstances, may require concerted action by hundreds of farmers.

Country Examples

Egypt: Egypt depends on about 2.95 million ha of irrigated land, mostly in the Nile Delta. The region is highly productive – the Aswan High Dam allows many farmers to produce two or three crops per year. However, inefficiencies in irrigation water conveyance and application led to problems of waterlogging and salinisation in many areas. By 1970, only 7% of the cultivated area was unaffected. Large-scale subsurface drainage work was undertaken and benefits were seen rapidly. Average wheat yields rose from 1.0 to 2.4 t/ha and maize yields from 2.4 to 3.6 t/ha. At least 2 million ha are now provided with open drains and more than 1.4 million ha with sub-surface drains. Many of the early systems are now in need of replacement.

Pakistan: Pakistan's irrigation network supplies an area of about 14 million ha. Despite suitable climate and good soils, crop yields are among the lowest in the world. One of the main causes is waterlogging and salinisation due to seepage from irrigation canals, poor irrigation practice and lack of drainage. By the early 1960s more than half the cultivated area was judged to be waterlogged, whilst 40% suffered from salinity. The widespread introduction of vertical tubewell drainage reduced the extent of waterlogging, which, however, is still a problem. Salinity is now controlled by a programme of sub-surface pipe drainage which currently covers about 2.5 million ha, expanding at a rate of 75 to 100,000 ha per year. Some 28% of the command area is still affected by salinity.

China: China faces serious water shortages in many regions as the result of population growth and growing competition for water between different sectors of the economy. To maintain the present level of per capita food supply, annual grain production needs to increase from some 420 million tonnes at present to 500 million tonnes. The Government has responded with a programme to increase the irrigated area from 48 to 53 million ha, and to reclaim 5 million ha of waterlogged and salinised land using sub-surface drainage.

India: Between 1950 and 1985, India's total net irrigated area increased from 21 million ha to 42 million ha. Despite the high investment in irrigation, drainage needs have been widely neglected. An estimated 5 to 6 million ha of agricultural land now suffer from waterlogging and salinisation caused by irrigation. Salinity and sodicity are the primary constraint to agricultural production. In Haryana State, salinization causes yield reductions of 30-40%.

2. ZONAL DRAINAGE CHARACTERISTICS AND CONSTRAINTS

The importance of drainage to sustaining agricultural production and the practices employed vary between countries, regions, and climatic zones. Problems and constraints are both generic and site-specific.

Surface drainage is designed to remove surplus surface waters, usually by open channels. It is used in temperate, humid and arid areas. Sub-surface drainage to control water and salt levels in the soil profile is applicable in temperate and arid climates, but salinity problems are more likely to occur in arid zones and attention to salinity control should be focussed in such areas.

2.1 The temperate zone

Most of the world's artificial drainage is concentrated in the developed countries of the temperate zone. In countries such as UK and the Netherlands virtually all the land requiring drainage is now covered, and new installations have become uneconomic. In South and East Europe, and parts of North America, some land still needs to be drained. Improved drainage is still rare in South America.

The main drainage problems result from long periods of winter rainfall which cause the groundwater to rise into the rootzone. Drainage allows early land preparation and planting in spring. Open drains are commonly used to collect surface runoff and reduce percolation into the rootzone. Subsurface drainage is used to lower the groundwater by a combination of open ditches and tube drains.

Research advances in the temperate zone are likely to address the development of more economic materials and methods.

2.2 The humid and semi humid tropics

Much of Central and South America, South and East Asia, as well as Central and Sub-Saharan Africa, fall within the humid tropics. Rainfall tends to be excessive in the rainy season and insufficient for agriculture in the dry season. The prevailing agricultural systems based on paddy rice have developed as a natural consequence of the climate, as the crop thrives in wet conditions. Irrigation assures a wet season crop and allows one or more additional crops, depending on variety and location.

Smedema (1997a) estimates that only 4% of agricultural land in the humid zone benefits from improved drainage. Drainage would improve production on a further 50 -100 million ha.

It is neither economically nor technically feasible to provide full protection against flooding. It is common to design against the one in five year event. Where drainage exists, its density is often low, leaving many areas inadequately served. Poor maintenance means that channels are commonly blocked when the need is greatest. High flood water levels in receiving rivers also commonly obstruct local drainage.

Rice uses more water than most other crops. As water supplies are over-exploited, it becomes increasingly important to reduce demand by diversifying cropping, at least during the drier part of the year. Most crops cannot tolerate a high water table. Suitable drainage design is therefore needed to achieve satisfactory yields from crops with different soil moisture requirements. Experience gained in developed countries is not directly transferable.

Even rice, although tolerant of standing water, is damaged by excess flooding lasting more than a few days. Drainage systems can improve yield, both by reducing damage to standing crops and by avoiding delays to the cropping season resulting from a need to replant.

Drainage challenges are related to the hydrological character of the zone and the need to achieve steady improvement in food production by increased cropping intensity and levels of productivity.

The aim of research and development in this zone must be to promote an integrated catchment approach to water management, including drainage which has a major role, due to the seasonal variability in rainfall. Water needs to be rapidly removed from the land surface during the wet season, but is then short during the dry season – provision of storage by management of drainage surplus is the key to providing water throughout the year in this zone. Water balances need to be drawn up on an areal (eg catchment or basin) and annual basis – integrated management is needed to facilitate drainage in wet seasons and provide water for irrigation in dry seasons.

2.3 The arid and semi arid zone

The role of drainage in this case is a dual one, being necessary for watertable and salinity control of irrigated land. Although both the extent of drainage and the technology are quite advanced, there are still large areas of agricultural land in need of drainage, and research developments still needed. Less than half of the drainage needs in the arid zone have been met, an estimated 10 – 15 million ha are still in need. Advances in drainage research and extent are necessary to prevent further loss of productive land.

One of the major differences between humid and arid zone drainage is that in the arid context both water quantity and water quality are of concern, whereas drainwater produced in humid areas is generally of good quality. Salts are of major concern as longterm over-irrigation leads to accumulation of salt which must be removed from the rootzone. Salts and other solutes are leached out of the soil profile into subsurface drainage systems, entering drainage water – this polluted drainage water must then be disposed of (see section 3.6).

Some 100 million out of the world's total irrigated area of 270 million ha lie in arid and semi-arid parts of the world, where agriculture depends primarily, or totally, on irrigation. In many areas, inefficient surface irrigation over decades has caused groundwater to rise to the point where rootzone waterlogging and salinity problems affect crop yield. The problem occurs in most of the principal irrigating nations including Egypt, Pakistan, India, China and Iraq.

Drainage is required to control both waterlogging and salinity, with minimal need for runoff and flood control. Rainfall is so slight that it has minimal effect. In terms of areal coverage, tubewells are the principal method of watertable control, especially in Pakistan and Northern India (Smedema and Ochs, 1998). Horizontal pipe drainage is more effective for controlling salinity.

Smedema and Ochs (1998) estimate that 20-30 million hectares of agricultural land are affected by waterlogging and salinisation. It is likely that the area affected will increase substantially in the next few years. Problems typically arise 20 to 50 years after the start of irrigation development. Less than half of the drainage needs to date have been met.

3. RESEARCH PRIORITY AREAS

Investment in drainage research has been relatively low compared to irrigation or other water resource management activities, and has primarily been carried out in the developed world, mainly in the temperate zone.

Other constraints to drainage include:

- Poor awareness of the benefits of improved drainage.
- Lack of appropriate, cost effective and sustainable solutions for developing countries.
- Inappropriate institutional structure and inadequate capacity.

Attention in these areas is critical to the future successful contribution of drainage to sustainable agriculture in the developing world. Investment in research and development is essential for progress in these areas, particularly the first two.

Appendix 1 includes a number of generic research themes identified in Sanmuganathan (1996). Appendices 2 and 3 include topics identified in IPTRID missions to various countries. In the present document, six key areas of research are proposed. These have been selected according to needs identified in more than one country or region of the developing world. They are as follows:-

3.1 Integration of irrigation and drainage to improve productivity with reduced water use
3.2 Quantification of drainage benefits and identification of optimum investment strategies
3.3 Preventative and remedial measures to improve drainage performance
3.4 Drainage and reclamation of problem soils

3.5 Drainwater disposal, reuse and related issues
3.6 Tools for planning and design of drainage

3.1 Integration of irrigation and drainage to improve productivity with reduced water use

3.1.1 Scale and nature of problem

Pressures on available water resources are increasing throughout the world. Competition between industrial, domestic and agricultural sectors is intense, particularly in arid and semi-arid areas. In global terms, agriculture accounts for 69% of water used, compared to 31% for the industrial and domestic sectors (Water Resources Institute, 1994). The agricultural water use in Africa and Asia (excluding former Soviet Union) is 88% and 86% respectively. Rapid expansion in urban and industrial development will increase water demands from these sectors, increasing pressures on agricultural water supply. There is an urgent need to improve efficiency of water use in all sectors, and considerable scope for increasing water use efficiency in agricultural water management.

'Traditional' approaches to irrigation water management need to be rethought to make most efficient use of available water. Current practices may result in application efficiencies as low as 30%, with overall basinwide efficiencies of 65-75%. Formal guidance is necessary to replace *ad-hoc* practices followed by farmers.

Water quality is increasingly of concern. Contamination of water supplies reduces the suitability of water for agricultural production and thus reduces efficiency. Any water management strategy to increase water use efficiency must embrace water quality issues. The reuse of drainage and wastewater for irrigation are important examples (Section 3.5).

3.1.2 Existing work

Under conventional agricultural water management**,** irrigation water is periodically applied to the surface and the excess is removed by the drains. In many instances, the soil moisture-holding capacity is small and water quickly drains from the soil profile before the crop has abstracted its full requirement. In other cases irrigators knowingly overwater. These processes promote losses and wastage of water supply. It is also asserted (Letey, 1993) that traditional water management practices result in ineffective removal of solutes, flow of leachates to groundwater and contamination of aquifers.

Irrigation and drainage should be integrated at the design stage. This can have positive effect both in terms of water savings, and on water quality. Under current design practice, water quality is rarely considered. Subsurface drains are set to meet the required drainage coefficient. The composition of drainage effluent is affected by the mixing of deep and shallow groundwater.

Grismer (1993) asserts that the shallower the drain, the smaller the contribution of deep groundwater to drainflow, although there will be site-specific variations. He claims drain depth for a given spacing should be reduced over conventional practice to improve the interception of solutes in the shallow groundwater and reduce aquifer contamination. Alternatively the drain spacing might be reduced.

Ayars *et al* (1997) suggest modifications to drainage design to make optimum use of existing water resources and reduce the impact of drainage flows on the environment. For example, simulations suggested the design minimum watertable depth for cotton under reasonable management should be reduced from 1.2 to 0.9m and the depth of drains from 2.4 to 1.5m.

Other work (Guitjens *et al*, 1997) suggests that traditional drainage design equations do not lead to good management of water quality. Models that account for transport and chemical changes in the soil water should be substituted for those associated with a traditional leaching fraction, or requirement concept.

Modified Drainage Design for Nile Delta

Studies have been done in Egypt on water management and modified subsurface drainage design in rice growing areas (El Guindy and Risseeuw, 1987). A large proportion of the irrigated area of the Nile Delta has been supplied with an intensive subsurface drainage system which was designed for the requirements of 'dry-foot' crops such as cotton, maize, wheat etc. However a large amount of land in the Delta is now producing rice, a submerged crop requiring radically different soil moisture conditions, grown in rotation as a summer crop. The introduction of pipe drainage systems in the seasonal rice growing areas caused considerable water management problems. Fields under 'dry-foot' crops require control of the watertable, whereas rice fields are kept submerged for most of the growing season. In rice fields, the presence of a subsurface drainage system that has been installed for other crops causes substantial water 'losses' through the system, and leads to large applications of irrigation water. Farmers block collector drains periodically by hand using straw, mud etc, leading to pollution problems for downstream collectors, waterlogging of dry-foot crops in upstream areas and local blockages by silts, debris etc.

DRI/ILRI[1] carried out a trial of a modified drainage design vs conventional drainage design. In a modified system the total length of the smallest collector pipes (15cm) is much greater than with the conventional system, but there are fewer of the larger, more expensive sizes (20 – 50cm). This is due to the larger number of subcollectors for the modified drainage system, and the smaller design drainage rate. The modified system was 3% cheaper.

It was concluded that the restriction of the outflow of subcollector units growing rice in the modified drainage layout would save at least 3mm/day. Over the total area of rice (420,000 ha) the saving in irrigation water would be 12.5 million m^3 per day or 1.5 billion m^3 per growing season. Thus the implementation of modified layouts in rice growing areas could contribute considerably to saving of irrigation water in Nile Delta.

In many cases significant financial savings can be made by installation of surface drains early on before waterlogging problems have developed and sub-surface drains become a necessity. Surface drains are typically a tenth of the price of sub-surface drains (Smedema and Tada, 1997).

Water management which encourages exploitation by the crop of shallow groundwater can increase water use efficiency and improve water quality. Controlled drainage is one approach which combines irrigation and drainage management to save water and improve water quality. Existing trials in a few locations need to be extended to determine the viability of the procedure in developing nations.

Research Priorities: Integration of irrigation and drainage to improve productivity with reduced water use

- Integration of irrigation and drainage design/management
- Controlled drainage and sub-irrigation (water table control to optimise productivity)
- Water management for increased water use efficiency
- Impacts of drainage design on drainwater and groundwater quality

[1] Drainage Research Institute / International Institute for Land Reclamation and Improvement

3.2 Quantification of drainage benefits and identification of optimum investment strategies

3.2.1 Scale and nature of problem

One of the key constraints to drainage development is lack of knowledge and awareness of the benefits that drainage brings. Quantitative information on the benefits of drainage to agriculture and to the wider environment, both in the arid and humid regions, is needed together with effective means of dissemination.

In order to justify investment, drainage must be justified in terms of a sustained increase in crop yield. Longterm predictions of soil and crop response are needed. In humid regions, more detailed data on the effects of waterlogging and surface flooding are needed. In the arid zone, existing information on crop and soil response to waterlogging and salinity needs extending.

In irrigated areas the balance between the investment in irrigation and drainage needs to be approached on an integrated and rational basis. Investment in particular aspects of the technology and/or management of irrigation may reduce the investment required in drainage. In other cases the drainage investment may allow re-use of drainage water or the control of water tables so drained water is regained by capillary rise. Little or no research has been undertaken in this area.

Better information will improve drainage design, water management and drainage water reuse strategies (see Section 3.5).

3.2.2 Existing work

Bradford *et al* (1991) modelled the effect of high saline watertables on crop yield to establish the likely benefits of introducing subsurface drainage. The study was limited to cotton and alfalfa in a limited range of conditions.

Finney (1997) found that cotton grew well in the Nile Delta, drawing on slightly brackish water at a depth of 1m, whereas in Sindh Province, Pakistan, the yield was reduced in all cases when saline groundwater was less than 1.5m deep. He presented outline data showing that the increase in crop yield to be expected from subsurface drainage in conditions of high watertable could be from 25 to 43% (cotton and maize), 11 to 25% (wheat) and 43 to 100% (citrus fruit).

There are very few data describing the effect of surface flooding on crop yields in humid areas. Drainage design uses rules of thumb such as: ‘Rice can tolerate excess water to a maximum depth of 150mm, provided the excess is cleared within 3 to 5 days’. In practice attention has to be paid to the risk of flooding relative to the stage of growth of the crop. Work in this area is sparse. Information on crops other than rice is even scarcer. Design is therefore necessarily conservative in many cases.

There is a huge body of work describing the response of plants to salts and ions in irrigation water and in the crop root zone (Ramage, 1980, Shalhevet, 1994). However, most of the data were obtained either in the USA, or under somewhat artificial conditions in Israel. Many questions remain in applications outside these countries. The the concept of leaching requirement has provided a basis for design of drainage schemes but very often the penalty for failing to achieve a particular leaching amount or indeed for over-leaching is unknown. In practice, leaching may not be needed at each irrigation but will be required at certain crop stages. Research is need to evaluate the risk of moving to a cyclic leaching strategy rather than the commonly adopted steady state leaching strategy. This is particularly important in situations where be drainage water is reused.

Research Priorities – Quantification of drainage benefits:

- Detailed information on crop response and tolerance to waterlogging and flooding for a range of important crops, especially in humid areas.
- The economics of drainage in the humid/semi-humid tropics.
- Crop yield reductions due to soil salinisation.
- Impacts of inadequate drainage on soil productivity.

3.3 Preventative and remedial measures to improve drainage performance.

3.3.1 Scale and nature of problem

Drainage systems throughout the developing world are performing poorly (Sagardoy, 1982, Le Moigne, 1989, World Bank, 1993b). Poor maintenance of surface and subsurface drains is a primary reason for under-performance. Sustained returns from investment in drainage infrastructure are not being achieved.

In developing countries the assigned budgets are invariably inadequate to maintain the drainage network. Financial problems are worsened by institutional structures that are unsuited to carry out good maintenance works. At present drains are often considered of low priority because the consequences of failure for agricultural production are not quantified or understood (Section 3.2). Policies to turn over the O&M of parts of system infrastructure to farmers are now being tried, but major parts of most systems will remain the responsibility of government departments in the forseeable future.

3.3.2 Existing work

Surface drainage waterways including channels, streams and canals form vital links in the drainage chain. Blockage or damage in any one component can reduce the carrying capacity of the system, causing backup in waterlevels and local or extensive flooding following runoff events. Common problems are siltation of waterways, blockage by debris or reduction in carrying capacity due to weedgrowth. Research into preventative and remedial measures is required. 'Soft' methods of drain maintenance, particularly for controlling vegetation, can be at least as effective, cheaper and more environmentally-friendly than traditional methods. They have particular application to open channels where access is difficult. Pilot trials are needed in the developing world.

Uninformed channel clearance procedures may have short-lived benefit or aggravate the problem. For example, desilting in an unplanned sequence can promote deposition and cutting vegetation at certain times in the growth cycle can encourage growth rather than reduce it (Smout *et al* 1997, Smailes, 1996). Dawson and Brabben (1991) identified possible strategies for weed control. Smout *et al* (1997) produced guidelines for weed control based on practices current in Kenya and Zimbabwe.

Since the resources available for maintaining drains are invariably inadequate for full clearance on a regular basis, procedures are needed to target funds to areas which will return the greatest benefit. Cornish and Skutsch (1997) developed a procedure for categorising the condition of the components of an irrigation system and assigning priorities for rehabilitation. Better means of linking component condition with system performance are still needed for drainage systems. The need for performance indicators to quantify the effectiveness of maintenance has been recognised by other workers (eg Zimmer and Vincent, 1997) with progress in some areas. For example, Bos (1996) prepared a set of performance indicators for irrigation and drainage covering water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economics and management.

Changes in the responsibilities for maintenance under government policies to devolve parts of public irrigation systems to farmers, require changed practices. At present there is no knowledge or guidance about the maintenance needed to sustain drains under farmers' management.

Research Priorities – Preventative and remedial measures to improve drainage performance:

- Performance indicators for drainage.
- Use of trees or plants to dry the soil and reduce drainage requirements (biodrainage).
- Procedures to prioritise maintenance and rehabilitation effectively and economically.
- Improved participation and institutional infrastructure for rehabilitation and maintenance.
- Adapting and introducing procedures developed in temperate zones which are designed to reduce the scale of maintenance tasks by intervening at the most effective times.

3.4 Drainage and reclamation of problem soils.

3.4.1 Scale and nature of problem

According to FAO (Rycroft and Amer, 1995) one of the most important challenges in agricultural water management is the drainage of clay soils. Poorly-draining vertisols impose a severe constraint on agriculture in a number of areas of the developing world. They exist under a wide range of climates, but the greatest area (83%) is found in semi-arid and arid climates.

Countries affected include: India with 60-80 million ha, and Sudan (50 million ha). Chad, China and Ethiopia have over 10 million hectares each. Argentina, Bolivia, Brazil, Cameroon, Ecuador, Egypt, Indonesia, Ivory Coast, Lesotho, Malawi, Mozambique, Nigeria, South Africa, Tanzania, Uganda, Uruguay, Venezuela, Zambia and Zimbabwe all have more than 1 million hectares.

Clay soils tend to be plastic and sticky when wet, to shrink on drying, and to swell on wetting. They are often poorly aerated. They are able to store large quantities of water in a fine porous matrix, making them particularly attractive for irrigated agriculture. However, the matrix is very poorly permeable, causing a very low saturated hydraulic conductivity.

Clay soils located in plains and basins often cause surface ponding, flooding and waterlogging after heavy rainfall. Soils having a high sodium content are prone to swelling and dispersion further reducing permeability.

These soils are difficult and expensive to drain by conventional means. Additional complications often include salinity, sodicity, swelling and shrinkage.

3.4.2 Existing work

Various techniques have been developed to drain clay soils, but very often these are uneconomic or ineffective in developing countries, due to differences in soil, climate or other factors. Wide variability in soil characteristics can also mean that a technique which is effective in one area will not necessarily work nearby.

Subsurface drainage often does not function well, even with close drain spacings. Mole drainage is an inexpensive and effective method of clay soil drainage and reclamation widely used in the developed world, but has yet to be widely adopted in developing countries. Generally confined to soils having a minimum clay content of about 30-35%, it involves the formation of a system of unlined pipes in the soil, usually of diameter about 75mm, at depths of 0.5-0.7m and at spacings of 2 to 3m (Spoor, 1995). In humid areas mole drainage systems are able to remove excess rainfall rapidly because of the system of fissures in the soil linking the surface directly with the mole channels. In arid irrigated areas where surface irrigation methods are to be used there is the need to develop techniques that close the cracks above the mole drain.

A recently-developed technique termed horizontal leaching (Armstrong *et al*., 1996) has potential to reduce the cost and time needed for reclamation of some heavy clay soils. The upper 0.7 – 0.8m soil is 'restructured' to increase its hydraulic conductivity, allowing water to move horizontally to drains at about 50m spacings. Salts are more readily removed from the soil matrix and can be drained off.

A number of site-specific techniques have been developed to drain poorly permeable vertisols, for example soils on the Deccan plateau in central India. Vertical chimney drains are used to intercept water seeping through a permeable band of weathered rock, known locally as murrum, located between the poorly permeable soil and the parent rock.

Research Priorities - Drainage and reclamation of problem soils:

- Effective techniques to reclaim saline sodic clays.
- Appropriate and economic methods for drainage and reclamation of heavy clays in developing countries.

Only a small amount of work has been undertaken in the area but the potential of the mole drainage technique and horizontal leaching for reclamation drainage demands that research is given a high priority. Internationally there is little current work on the drainage and reclamation of sodic or saline clay soils. The 1998 international drainage conference in Florida includes only five out of 88 papers specifically directed at this topic. However, it is an area where the UK has very obvious expertise not available in other countries.

3.5 Drainwater disposal, reuse and related issues.

3.5.1 Scale and nature of problem

The safe disposal of drainage water, commonly polluted with salts, pathogens, heavy metals or other contaminants is an issue of increasing concern in many areas. Disposal must take account of human health, agricultural production and habitats downstream. In Pakistan and India, difficulties of disposal may prevent the commissioning of new drainage projects, increasing problems of waterlogging and salinity in the region.

In arid and semi-arid regions, maintenance of the catchment salinity balance is critical to sustainable agriculture. For long-term equilibrium, the quantity of salts in irrigation water introduced into an area must be balanced by an equivalent amount leaving in the drainage water. The soil must be leached when saline water is used, to prevent the accumulation of salts. According to some workers (Shalhevet, 1994 and Meiri et al, 1982) periodic leaching is more effective than leaching during every irrigation. Although guidelines exist, some uncertainties remain to be resolved. Studies in the Nile Delta, Egypt (Abbott and El-Quosy, 1996a) suggest that in places salts are not being removed sufficiently, and are accumulating in soils.

3.5.2 Existing work

There are several approaches to disposal of drainage water from irrigation schemes developed in the USA and Australia, that may be modified for use in developing countries. These include:

- evaporation ponds to dispose of saline drainage water.

- aquaculture systems.

- direct injection of drainage water into deep aquifers.

- biodrainage. It may be feasible to recycle drainwater through a series of agro-forestry systems including salt - tolerant cotton, eucalyptus woodland and salt- tolerant halophytes before discharging to evaporation ponds. A major advantage of this system is that the quantity of water is reduced to more manageable volumes (Tanji and Karajeh, 1993, Smedema, 1997b).

Another option is to reuse drainage water for agricultural purposes. This can reduce disposal costs and save water but careful water management is needed to avoid serious soil degradation and crop damage, or adverse effects to human health and the environment. Salts and toxic ions can affect crops and soils. Other pollutants such as heavy metals and pathogens pose serious risk to human health. Careful management is essential because the dangers are not well understood by water resource planners, technicians and farmers.

Reuse may require treatment or dilution to bring pollutant levels below tolerable limits. Guidelines are needed on appropriate dilution and blending strategies required in different situations (Abbott and El-Quosy, 1996b). Cyclic reuse of water does not appear to be a practical proposition in most developing countries.

Research Priorities - Drainwater disposal, reuse and related issues:

- Appropriate and economic methods for disposal of low quality water– constructed wetlands, evaporation ponds, aquaculture techniques adapted for developing countries.

- Development of operational guidelines for drainwater reuse.

- Optimal strategies for conjunctive use of drainage and fresh water.

- Leaching strategies to optimise water use efficiency and pollutant removal.

- Water quality monitoring procedures appropriate to developing countries.

- Techniques to minimise impacts on soil productivity of reusing drainage water.

3.6 Tools for planning and design of drainage.

3.6.1 Scale and nature of problem

As discussed in Section 3.1, there are considerable benefits to be gained from the integration of irrigation and drainage design and management. There is also a particular need to support and build up institutional capacity in drainage planning and design. Suitable tools to assist engineers to identify and analyse problems and to complete effective designs, can play an important role in strengthening institutional capacity.

3.6.2 Existing work

Drainage simulation tools are useful aids to improved drainage design and operation. One example is DRAINMOD (Skaggs, 1978) developed primarily for humid regions of North America. However application in semi-arid regions (Gupta et al, 1993) has been limited to date. Benefits in terms of water-saving and protection of groundwater are not assessed.

Models dealing with large drainage basins require large amounts of data and tend to be time-consuming to learn and run. Many were developed for research purposes rather than as design tools.

Examples are LEACHM (Wagenet and Hutson, 1989), SWATRE (Feddes et al, 1978), and DRAINMOD (Skaggs, 1978).

Existing aids for irrigation design typically do not link farmers' management of irrigation and soil with the drainage basin. An exception is the MIDAS irrigation design package (HR Wallingford, 1996) which provides assistance with essential design operations such as analysis and plotting of topographical survey data and production of working drawings. However, MIDAS does not include a comprehensive drainage design module.

The DrainCAD and CanalCAD models (Liu and Feyen, 1993) are directed to irrigation and drainage system design, but they do not simulate the effects on watertable and soil salinity.

The Colorado State University Irrigation and Drainage (CSUID) model is an example of a simulation model, which can be used for the design and management of irrigation and drainage systems (Garcia et al, 1995).

Research Priorities - Tools for planning and design of drainage:

- Regional planning models that predict future drainage requirements for watertable and salinity control.
- User-friendly models that allow engineers to simulate at field/tertiary block scale the medium-term effects on watertable and soil salinity of various possible interventions.
- Guidelines to choose between vertical and horizontal drainage.

4. CONCLUSIONS

Six priority areas for drainage research have been proposed. These have been selected according to needs identified in more than one country or region of the developing world. As highlighted in this paper, research needs vary between countries and regions. Thus, although priority research areas have been identified, they have not been ranked. (In the case of some countries, the more specific needs identified in appendices 2 and 3 will take priority.)

The proposed priority areas are:

- Integration of irrigation and drainage to improve productivity with reduced water use
- Quantification of drainage benefits and identification of optimum investment strategies
- Preventative and remedial measures to improve drainage performance
- Drainage and reclamation of problem soils
- Drainwater disposal, reuse and related issues
- Tools for planning and design of drainage

Research must be proactive, with the ultimate aim of optimising the use of water and minimising costs. Growing populations and increasing pressures on available land and water make it imperative to make better use of available resources. Innovative methods and integrated strategies are needed, to develop marginal lands and water sources, at one time considered unfit for use.

It is clear that the history of drainage research has been one of reactive response. Drainage has been seen as an option in arid irrigated areas, and only recently acknowledged as a key part of total water management in humid areas. The challenge for research now is to continue integration between water resource management and drainage in humid areas, and to initiate integration in arid areas.

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Appendices

Appendix 1

Generic research topics

Appendix 1 Generic research topics

ODA's draft outline strategy paper on irrigation and drainage (HR Wallingford, 1996) identified the following broad themes of research in drainage/reclamation:

1. Methods to integrate the development of drainage and irrigation to maximise productivity.
2. Effective techniques to reclaim saline sodic clays.
3. Water management techniques to minimise impacts on soil fertility of using marginal quality water.
4. Innovative methods of disposing low quality water from irrigation systems.
5. Integrated catchment planning and management of irrigation, drainage and landuse systems for the control of rain and/or irrigation induced waterlogging.

In addition it identified a need for:

6. basic information to formulate policies.

Appendix 2

Country research topics identified by IPTRID
in arid/semi-arid areas

Appendix 2 Country research topics identified by IPTRID in arid/semi-arid areas

Egypt and Pakistan

- Integrated programmes for improvement of technology for planning, investigation and design of sub-surface drainage projects:

- Improvement of drainage technology and installation: pipe drainage

  Introduction of new materials
  Envelope materials
  Tubewell drainage

- Improvement of drainage operation and maintenance

- Drainage of problem soils

  Heavy fluvio-marine clays
  Unstable soils
  Areas under artesian pressure
  Desert fringe areas
  Areas with rice cultivation
  Areas with shallow barriers
  Sugarcane areas

- Rehabilitation of old drainage schemes

- Environmental aspects

  Water quality
  Reuse of drainage water
  Use of wastewater

- Monitoring and evaluation of drainage systems

Mexico

- Modernisation of farm drainage technology
- Conjunctive use of surface and groundwater for irrigation and control of groundwater and salinisation levels on irrigated land
- Computer programs dealing with irrigation and drainage problems
- Reuse or disposal of drainage water
- Pumped drainage vs horizontal drainage
- Wind powered drainage pumping
- Procedures for monitoring salinity and drainage conditions in the irrigation districts
- Monitoring and measurement of saline lands with remote sensing

Appendix 3

Country research topics identified by IPTRID
in countries spanning climatic zones

Appendix 3 Country research topics identified by IPTRID in countries spanning climatic zones

India

- Salt disposal modelling study for irrigated basins in north-west India.
- Procedures for establishing and managing phreatic fresh water lenses in saline groundwater zones in the Indo-Gangetic plains
- Pilot project for waterlogging control for the eastern plains and deltas
- Pilot study on conjunctive use in the Sri Rama Sagar project

China*:*

The top-ranked priorities for China were:

- Salinity and drainage design guidelines for arid, semi-arid and semi-humid zones
- Field drainage design guidelines for waterlogging control in South China

Other needs were:

- Development of optimal strategies for conjunctive use of saline and freshwater
- Salinity control and drainage design guidelines for arid, semi-arid and semi-humid zones
- Waterlogging and salinity control
- Integrated monitoring, data gathering and processing of drainage data
- Optimisation of design and operation of drainage systems
- Development of a field drainage simulation model of rice based diversified cropping systems
- Field drainage design guidelines for waterlogging control in South China
- Environmental improvement through drainage
- Technology for maintenance of drainage systems.

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