than in countries less well-endowed with fossil fuels.

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Irrigation water management: Course summary

1 Summary : Why do farmers irrigate? : to obtain a crop or to obtain higher crop yield; to obtain improved crop quality. Crop yield improvements from:

providing water, when there is insufficient soil water/ rainfall for growth, especially germination;

providing water to help make soils workable viz rice;

preventing weed competition viz rice;

controlling soil temperature in spring for rice and mountain agriculture;

providing frost protection to fruit crops, by coating blossom with ice to provide heat and prevent heat loss;

controlling application of small amounts of fertiliser and pesticide at critical times of crop growth;

inducing frost heave, to improve conditions for crop growth, viz apples in Shaanxi.

There are crop quality benefits from : providing evaporative cooling of fruit trees at times of high solar radiation; preventing or controlling disease infestation in crops, viz common blight in potatoes, alternaria blight in pistachio orchards.

2 Summary : What helps indicate the need for irrigation?

Crop: Need knowledge of when and how much water to apply. Plant behaviour is linked to temperature control, via control of evapotranspiration, by regulating stomatal opening. Specific aspects of plant growth indicate appropriate timing of irrigation.

Soil: Soil provides a reservoir from which water can be drawn by plants. Crop rooting depth and amounts of readily-available water, within the soil profile, identify how much water can be used, before irrigation becomes necessary. Direct/in-direct measurements of soil water changes can indicate the correct timing and maximum amount of irrigation water supply.

Weather: Daily meteorological measurements of evaporation, mean

temperature, wet and dry bulb temperature, wind-run, sunshine hours and rainfall help calculate soil water balances. Accounting for soil water changes, through daily tabulation of actual evapo-transpiration, rainfall and irrigation, identifies levels of soil water deficit or depletion. Irrigation practice might fully or partially re-fill the soil water deficit.

3 Summary: What other services are required, in association with irrigation scheduling advice, especially for privatised services? Crop specific advice is provided by private consultants or by self-financing government services. Irrigation scheduling advice may be linked with recommendations for weed and pest control or fertiliser recommendations. Private consulting has been encouraged in the USA by large farm sizes, coupled with reduced farm labour, especially those farms growing high value and high-risk crops. Prices paid for services are around 1-2% of the gross income of the crop. Direct soil water measurements are often an important part of private irrigation scheduling services. Organisations providing private services have good communication with their customers, typically through grower newsletters. Associated services to growers might include planning new installations.

Encouragement of Water User Associations, outside China, has emphasised specific ingredients judged necessary for the success of the transfer of large irrigation scheme assets to such associations. These ingredients include:
(i) financial management by the WUA (ii) autonomy (iii) adequate capacity in terms of technical and managerial skills along with functional and suitable physical infrastructure (iv) reliable water supplies.

4 4 Summary: How do irrigation canal systems operate and how is water obtained by farmers, in China? Large irrigation schemes such as ZIS either provide water to sub-branch canal groups, or to small size reservoir and pumping stations, with some additional water provided to managers of ponds. In the first two cases, 3-5 staff are responsible for water application, measurement, organising maintenance of canals and machinery, as well as management of trees along the canals. For small size II reservoirs covering an irrigated area of 200-400 ha, there might be just a water manager and an electrical worker. There is typically 1 pond per 0.8 ha, across the scheme. Pumping from groundwater is typical of Songjiang County (Shanghai). The average area of irrigation project is 47.3 ha, with an irrigation to power ratio of 3.04 ha/kW. Generally, each irrigation project is run by 6-7 farmers, with one in overall charge, one technical worker and 4-5 field irrigators. The person in charge and the technical worker are employed by the village, while the irrigators are appointed by the production team, that directly benefit from the village irrigation. On average, each technical worker takes care of an area of 400 ha.

In Yang Lang Gou village of Tai An city of Shandong, more than 50 dams, motor-pumped wells and water diverting projects have contracted to 7 professional households for supply of irrigation water. Village Committees contract such projects for 15-20 years. During this time the Village Committee has the authority to supervise the professional household. The household has the right to run the business and collect water charges. A part of these charges, representing depreciation costs, are given to the Village Committee for renewal funds. Some villages have only contracted hydraulic structures to the professional households. The latter provide pumps and electrical equipment themselves.

5 Summary: What are the financial costs of obtaining irrigation water in China?

Farmers at ZIS either make payment direct to the professional management of Zhanghe reservoir (sub-branch management groups) or to the Township water management station (small size reservoir and pump stations). In 1993, the charges were based on acreage as15 Y/ha and on usage as 0.021Y /m^3, for both situations. Payment of individual water managers was arranged as part from farmers fees, part from benefits of cultivated and land and access to fish ponds provided by the village and part for income derived from trees along canals. In Songjiang County, the estimate of irrigation costs in 1991 was 137.6 Y/ha, with 60% representing wages and 23% energy costs. The World Bank survey of Burt and Styles suggests an average irrigation water charge of around 30 \$/ha with an average charge based on usage of 3 \$/10^6 m^3.

6 Summary: What defines efficient and effective irrigation? Irrigation efficiency is the ratio of (volume of irrigation water beneficially used) to (volume of irrigation water applied - Δ storage of irrigation water). Water applied for leaching represents beneficial use, while water for seepage and deep percolation is not. Overall irrigation efficiencies combine measures of canal conveyance efficiencies, as well as in field irrigation efficiencies. Extra water may be applied to allow for non-uniformity of application, but more commonly, in-field designs are based around achieving a minimum level of distribution uniformity. Distribution uniformity is the ratio of (average low quarter depth of water infiltrated) to (average water depth infiltrated). Effectiveness is a measure of how well an activity achieves the intended purpose. Water use efficiency and water productivity can have several meanings.

7 7 Summary: Which irrigation technique/equipment is best suited to meeting particular needs? With the likely exception of paddy rice, either surface or overhead irrigation systems are practicable for most crops. Relatively flat and heavy land favours surface irrigation development, while undulating land with light soils favours overhead irrigation. Costs can be comparable. This occurs when the extra capital costs, of land development for surface irrigation, are matched by the extra running costs associated with energy, for overhead irrigation. Either basin or furrow irrigation will be suited to flat topography, with choice between furrow and border strip methods being determined by crop cultivation practice. Use of drip irrigation is likely to be most successful in medium textured soils, with a reasonable silt fraction. In China, drip applications have included greenhouse vegetables, grapes, pears and peach trees.

8 Summary: What are the typical irrigation regimes for important Chinese crops?

Irrigation water requirements depend on crop water requirements and effective rainfall supplies. Additional water supplies are needed for paddy rice, to cover the percolation and deep seepage losses associated with ponded water. These losses depend on soil texture and ground water depth and can range from 0.3 4.8 mm/day. Variation of evapotranspiration values between years is not often considered for planning purposes. However, a variation of ± 25% has been reported for either dry/warm years or wet/cool years, in relation to average figures for mid-rice grown in Hubei. Irrigation water requirements are typically calculated for effective rainfall, which is equally or exceeded with a particular level of probability, typically 75%. A table beneath illustrates the variation in irrigation water demand, depending on rainfall probability values for Beijing.

Crop	Irrigation req. 75% prob. Rain (mm)	Irrigation req. 50% prob. Rain (mm)	Irrigation req. 10% prob. Rain (mm)	Months requiring irrigation
W Wheat	357	304	202	March-May
Paddy rice	887	763	585	May, August-September
S Maize	132	67	1	June, September
Cotton	188	131	49	June-July, Sept. Oct.

Y	1050
Vegetables	

There appears to be a measure of controversy over the need for ponded water, when growing paddy rice beyond the early tillering stage. 80-110 mm of water is typically needed for softening the soil, prior to transplanting. At transplanting, a depth of 15-20 mm is recommended, with additional water to match seepage losses. Ideal conditions, for recovery of transplants in the turning green stage, are said to be 20-40 mm depth for early rice, increasing to 45-50 mm for late rice. Ponding to a depth of 10 mm in the day, with no water supply at night, is recommended in the early part of the tillering stage. The ear formation and flowering stage is the stage most sensitive to lack of water, but water supplies representing at least 80% of soil saturation are claimed to be adequate for maximum yield. Some authors say water might be ponded to a depth of 20 mm at this stage.

9 Summary: What water saving measures have proved successful in China?

Research from Jiangsu and Shandong provides evidence for the claims that, after the turning green stage, a standing water surface is not required for subsequent crop stages of paddy rice. It is said that soil water should be controlled between saturation and 60-70% of saturation. Using this approach, the researchers attained an equivalent mean rice yield of 9.8 t/ha from lysimeters, over a period of 9 years. The typical amount of water used, including that for land soaking, is suggested to be only 337 mm. Comparison of water needs, over 9 years, of either conventional flooding irrigation or the controlled water saving irrigation practice are given below.

Practice	Leaf transpiration (mm/annum)	Interplant evaporation (mm/annum)	Field seepage (mm/annum)	Water requirement (mm/annum)
Flooding irrigation	331	126	543	999
Water-saving irrigation	215	98	279	592

Similar water saving experiments in Zhejiang, have emphasised the associated power savings linked to water savings (150 kWh/ha) and labour saving (10 work days/ha). Researchers claim an improvement from only 15%, to as much as 20-60% effective rainfall, associated with the water saving irrigation. The average amount of water saved over 8 years of consecutive trials of combined early and late rice was 201 mm, representing a 32% saving over conventional irrigation. Average water savings, measured at 7 different sites in 1997, were 112 mm for early rice and 95 mm for late rice, representing savings of 49 and 38%

respectively. In all water savings experiments, herbicides are necessary to compensate for the lack of weed control by standing water.

Opportunities for water saving are considerably increased when rice is dry seeded. Cultivation requirements are also rather different, with fields being ploughed in autumn then irrigated in winter to promote break-down of clods by freezing and thawing. Varieties being used are different and yields are some 15-20% less than paddy rice. In contrast water and labour savings are said to be 50% of the equivalent paddy requirements. The table beneath gives irrigation supply figures for north Henan.

Growth stage	Days	Dry seeded rice (mm)	Transplanted rice (mm)
Transplanting to tillering	24	189	408
Tillering to jointing	28	103	332
Jointing to heading	27	187	399
Heading to maturity	41	192	240
Entire season	120	670	1380

* Note water use for puddling is 250 mm, with a further 150 mm applied at the end of the season, to compensate for drying out.

10 Summary: What irrigation operation and maintenance procedures are needed? US irrigation districts are publicly-owned agencies with similar responsibilities to those of the Conservancy Bureau in China. Elements of operation and maintenance might be compared. In US districts, managers should maintain good safety programmes, use technical and administrative staff as required, in addition to the basic responsibilities of organising services and motivating staff. Operational aspects include storing, conveying and delivering water, as well as disposal or re-use of drainage water. Written copies of conditions of water service should be provided to each farmer. Careful recording of water requests is judged important.

It is important that specific types of drainage problem are recognised, unwanted runoff is intercepted and that arterial drains remain fully operational. Clear prioritisation of maintenance work is strongly recommended. Silt removal from canals commonly represents the greatest maintenance cost, though potential requirements of reservoirs should not be ignored.

11 Summary: What are the social and environmental impacts of irrigation? In some instances, the provision of large-scale surface irrigation facilities has made the environmental heath conditions of a community considerably worse. Control of schistosomiasis japonica and filariasis remains important in China, as the search continues for effective vaccines. Knowledge of the schistosome life cycle is important, in suggesting opportunities for control.

The problems of both saline and sodic soils need to be recognised, as well as their interaction. There is an inevitable requirement for drainage of salts, from irrigated areas of semi-arid and arid regions. Salts are also often contained in the return flows from other irrigated farming. While sodic soils suffer from loss of tilth and soil structure, the saline soils impose constraints on water uptake, with considerable variation in the susceptibility of individual crop species to saline conditions. Salinity of a soil sample is measured by the total dissolved mineral substances in a water extract, taken from a saturated sample. This is usually based on a measurement of electrical conductivity, expressed in deci-Siemens/m. Sodicity is measured as exchangeable sodium percentage or sodium absorption ratio. Salt management is achieved through additional irrigation water, determined from values of leaching requirements.

Instances of increased levels of drainage, associated with irrigation schemes, in both the US and Israel, has promoted the un-wanted release of selenium in one instance and phosphate in the other, leading to environmental damage.

Salt-water intrusion continues to be a concern in the coastal areas of China. This has been associated with excessive groundwater development by farmers, who use the water for irrigation. Over-pumping of ground water, particularly in the karst areas of China, has occasionally led to significant economic loss, associated with land subsidence.

12 Summary: Do alternative wastewater resources provide practicable options?

Taking estimated (capital and operating) costs in 2000, at around 1.7 Y/m^3 for new agricultural water supplies in northern Chinese cities, helps suggest the level of cost which might be associated with wastewater treatment and recycling. This represents an upper limit, based on forecasts made in 1994. Urban sewage can be used either to recharge groundwater and so receive a measure of treatment in the process, or it may be directly re-used. Direct re-use in agriculture, without treatment, is known to be harmful to people. As a result of direct recycling of wastewater, investigations have shown that 60% of some 257,000 ha of land in 7 North China cities has become contaminated. Related groundwater has become so polluted that it can no longer be used as potable water. In the 1990s, marginal (capital and operating) costs of large scale sewage treatment for re-use were put at 0.7 0.6 Y/m^3or at 1.3 1.1 Y/m^3, if additional investments in drainage and financial consequences of pollution loads are included. Costs relate to Beijing and Tianjin. If these additional investments and consequences can be removed, by localised recycling, then additional payment might be due to the organisers. These figures put the maximum expenditure on localised recycling at around 2.3 Y/m^3, with the farmer only paying 1.7 Y/m^3 for delivered water. In 1994, the UNDP report suggested pricing treated wastewater at 0.7 times the clean water cost. In this case, either 1.8 Y/m^3 or 1.2 Y/m^3 becomes the target wastewater overall investment and operating cost for localised recycling.

Appropriate combinations of crops are required to receive treated wastewater, if above ground storage is to be avoided throughout the year. Trees crops might be expected to receive treated water throughout the dry winter months. While small-scale municipal sewage might be expected to be free of heavy metals, there are still some problem chemicals. Sodium and boron have been identified as problems elsewhere. Contamination by volatile phenols is a particular feature of wastewater, which has previously been recycled in China. How important this is, at the small scale, needs to be clarified. A complete picture of tolerable chemical composition is given in the Chinese State Water Quality Standards for irrigation.