China – UK, WRDMAP
Integrated Water Resources Management Document Series

Advisory Note 3.1/2: Practical Techniques for On-Farm Water Saving

3. Demand Manage-ment

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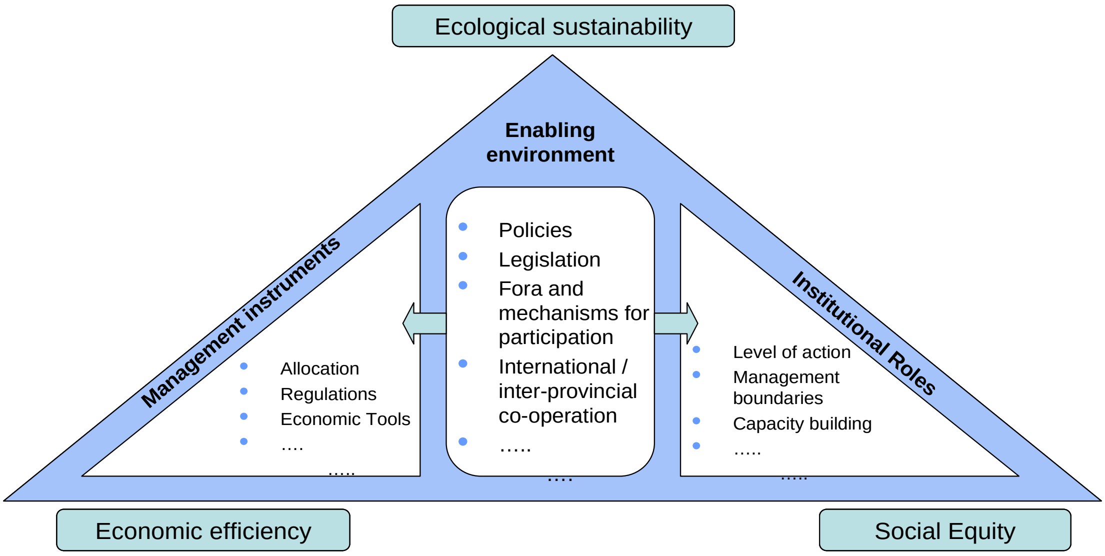
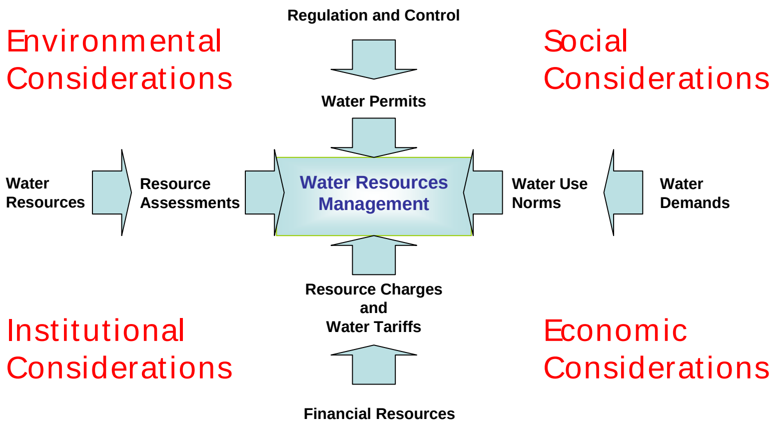
Mott MacDonald

Integrated Water Resources Management (IWRM)

(Basics after Global Water Partnership)



Driving Elements of Integrated Water Resources Management



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Summary: This document is aimed at farmers and Water User Association leaders, to support the introduction of practical and feasible water saving knowledge and techniques.

This document should be read in conjunction with the Advisory Note 3.1/1 'Agricultural Water Saving Techniques' in the same series, which introduces water saving experiences, analyzes crop water demand and agricultural water saving potential and develops locally appropriate agricultural water-saving techniques for use at WAB/WMS level.

This document has the following sections:

- General knowledge of on-farm water saving
  - Purposes of irrigation and water saving procedures
  - Ways to achieve water saving
  - Soil water and irrigation
- Water saving techniques
  - Crop pattern change
  - Water saving in fallow season
  - Land preparation
  - Furrow irrigation and ridge planting
  - Deficit irrigation
  - Greenhouses
  - Straw mulching
  - Plastic mulching
  - Irrigation water saving with pipe distribution system
  - Dripping irrigation

The Ministry of Water Resources have supported the Water Resources Demand Management Assistance Project (WRDMAP) to develop this series to support WRB/WABs at provincial, municipal and county levels in their efforts to achieve sustainable water use..

1 General Knowledge of On-Farm Water Saving

Water scarcity is the main barrier for socio-economic development and eco-environment development in North China, especially in the Northwest. Due to over-abstraction of water, environmental problems such groundwater level declining, natural oasis shrinking and desertification have taken occurred in parts of China. This then restricts local socio-economic development.

Agriculture is the major water user, which accounts for 90% of total water uses of sectors in inland river basins in Northwest. Due to greater economic returns from urban and industrial water use, for example, current average GDP per unit of industrial water use is about 25 RMB, which is much higher than economic returns of agriculture that per unit of water can produce no more that 1kg grains, the water allocated to agriculture is reduced gradually. Development of water-saving irrigation has become the necessity for long-term sustainable development of agriculture in China.

1.1 Purposes of irrigation and water saving procedures

The main purpose of irrigation is to meet the requirements of the plants being grown, while getting profitable yields. Thus, any losses of irrigation water that are not relevant to crop yields should be controlled.

The goal of water saving for irrigated agriculture, then, is to control the unbeneficial losses of water during the entire process: from water delivery to irrigation and on-farm use.

Minqin County, Gansu Province – water scarcity

Long term water shortages in Minqin have meant that farmers are required to reduce the area irrigated (sufficient water for a crop area of 2.5 mu/person is envisaged). This has lead to changes in land use such as conversion of agricultural to grazing land, and also well closures and changes in canal management.

"Save the Minqin Oasis immediately!"

1.2 Ways to achieve water saving

- **To reduce evaporation from soil.** Water evaporates from the soil during the growing season; this water loss produces no yields. Because in Northwest China there is only one growing season per year, the fallow season is relatively long. After the harvest and before planting, ie. during the winter when crops are not being grown, evaporation of irrigated water is even more unbeneficial. Therefore, a reduction of water evaporation from soil should be given most attention for water saving.
- **To reduce seepage.** Plant roots are mainly distributed in layers of soil less than 60cm, although during the peak period of plant growth roots can reach 90-120cm. Water is mainly absorbed from the surface layer, so on-farm irrigation mainly covers soil about 60cm from the surface. Too much irrigation will recharge groundwater, which will not benefit crops.
- **To reduce transpiration of plants.** There are many ways to reduce plant transpiration, but for main crops such as wheat and maize, water deficit at two stages can be applied: one is during late stage of seedling and before jointing, the other is late stage of milking.

1.3 Soil water and irrigation

Question 1: The more water that is irrigated, the better it is for crops? What are the disadvantages of too much water irrigated?

Too much water irrigated actually is no good to crops, and to farmers. Reasons include the following:

- Too much water irrigated results in groundwater recharge. From a regional water cycle perspective, water is not lost; water seepages from soil can be used by local or downstream farmers for irrigation. However, from the farmer's perspective whose water use entitlements are limited, large seepages will reduce irrigation water for themselves.
- Water seepages from soil convey large soil nutrients into the groundwater, especially nitrogenous fertilizer. This will not only reduce the effects of fertilizer, but will also result in nitrate pollution of groundwater. In China there are lots of wells in which nitrate nitrogen of groundwater exceeds standards. If people drink this water, risks for people to getting sick, such as digestive tract cancer, will increase. Further, such polluted water is very harmful to children. So scientific irrigation should be applied, both for saving water and fertilizer, and to protect human health.

Question 2: How much water is actually used for irrigation?

- Soil likes a water container, so how big is this container? Total water volume storage in soil of 50cm depth is about 22cm in depth. The more the soil is sandy, the less water it stores. For the water of this 22cm deep, 6cm will flow into the lower-layer soil ('gravity water') within 1-2 days after irrigation. About 4cm can never be absorbed by crops (below wilted coefficient), so the real beneficial water in soil is 12cm deep. Water in soil is about 8cm deep when farmers find that crops wilt at noon (except 4cm cannot be absorbed, so beneficial water is 4cm deep). If irrigation happens at this time, then appropriate irrigation volume is about 7-9cm deep, which is equivalent to 45-60 m3 per *mu*. (A *mu* is a Chinese measurement of area, equivalent to roughly 666 square meters.)
- If irrigation volume during crops growing season is more than 60m3 per *mu*, surplus water will flow into lower soil layers or groundwater where crops cannot absorb water. That is to say, **water volume/irrigation should not be more than 60m3 per *mu*, otherwise, surplus water will be lost**.

Question 3: Typically, a single round of irrigation in places where water saving is relatively high is about 40m3/mu. However, this is not applicable to Northwest China. Why?

- At many places where water use is relatively low, water volume/irrigation is typically 40m3 per *mu*. This is not applicable in the northwest of China, however, because flood irrigation is used there. During flood irrigation, the area of one plot is at least 1 *mu*, or even as big as 5-8*mu*. This plot area is so large that the ground surface is not level, and there are great differences in water depth. In some places water depth may be 30cm, in others the water might already be recharged to groundwater, while in still other places there may be no irrigation at all. What to do with this? Only apply more water. Crops where irrigation depth is low will suffer from water scarcity soon after the irrigation. The solution will turn to more rounds of irrigation. So it is not abnormal to irrigate about every ten days with 80-120 m3 per *mu*.

- Flood irrigation is applicable when water rights are not identified. When water rights are limited, however, in order to improve water-saving irrigation without reducing yields, there is no other choice but to do land levelling and reduce plot size.

2 Water Saving Techniques

It will be much easier to undertake water saving management with knowledge of how water is lost. With water rights system implemented, total water allocations for one household, and for one unit of land area can be identified.

2.1 Cropping pattern changes

Water requirements of different crops are quite different, so crop pattern changes can reduce water use.

Take main crops in Liangzhou District for example, 6 rounds of irrigation are needed for spring wheat, 7 for spring maize, while intercropping of wheat and maize need 8 rounds of irrigation. For vegetables of which growing seasons are short, water requirements are smaller. However, if 2-seasons vegetables are to be planted in one year, water use would then exceed 8 irrigations. Vegetables in greenhouses would need more irrigation, though with dripping irrigation, pipe irrigation, smaller plots and the water saving effects of greenhouses, water use of irrigation can be reduced greatly. In all, water requirements of crops differ significantly.

In the Shiyang River Basin (SRB) of Gansu Province, a programme of well closure and farmland reduction has been in operation since 2007, with a water allocation quota of 410m3/*mu*. Based on field surveys, the farmers' first coping strategy was to reduce planting area, especially the planting area for intercropping wheat and maize which consumes lots of water. This is a typical example of water saving through changing the cropping pattern.

The following table represents annual water usage and yield for cropping patterns, based on observations and calculations.

Table 1 Cropping patterns

	Annual water use of irrigation (m3)	**Yield (Kg/*mu*)**
Spring wheat	450	350
Maize	510	750
Intercropping of wheat and maize	570	Wheat: 350 Maize: 550

Compared to monoculture of wheat, water use of intercropping per *mu* is 120m3 more, but yield per *mu* is 550kg (maize) more.

Compared to monoculture of maize, water use of intercropping per *mu* is 60m3 more, but yield per *mu* is 150kg more.

So from productivity per unit of water, intercropping is most cost-effective.

Compared to water allocation quota, 410m3/*mu*, water consumption by intercropping is 160m3 more. What then are measures to cope with it?

The most essential measure is water saving, to reduce water volume per irrigation. 40-50m3 per irrigation is enough. In addition to simply lowering water volume, crop pattern changes may also be effective, including:

- Moving parts of the vegetable cultivation into greenhouses, which will save some irrigation water. The saved water can then be used for intercropping of wheat/maize
- Making some plots fallow while others have intercropping of wheat and maize
- For parts of maize plots, changing winter irrigation to irrigation in early spring. This will reduce irrigation volume and allow other plots to go on wheat/maize intercropping.

In general, the purpose of crop pattern change is not to close down wells and reduce farmland area. Rather, it is to improve productivity of limited water and economic benefits.

2.2 Water saving in fallow season

Only one season of wheat and maize is planted in the Northwest every year. There is a long winter after the harvest. Evaporation still happens even when there are no plants in field, and thus a great deal of water in the soil is lost. The more the water is lost, the more water is needed for the next irrigation; this is the reason why water volume for winter irrigation is more than 120m3 per *mu*.

Water saving in the fallow season is the most crucial out of the whole year, and has the largest potential for water saving. Measures should be taken to try to hold soil moisture during fallow seasons.

What is the water saving measure to keep soil moisture during the winter? First, a widely applied approach is straw mulching, which is applicable where straw is not of much useful value. It is very effective for water saving during seasons without crops and next year crop growing period. Straw mulching will improve fertility of the soil, and it will reduce applications of fertilizers in long term. However, straw mulching requires the use of machinery. In China there are many types of straw mulching machines produced so far, but farmers' income is low in the Northwest, so they need support and subsidies from the government or agriculture machine extension departments for applications of the straw mulching machines. Further information about straw mulching techniques is included later in this document.

Second, another approach is to avoid farrowing, shallow harrowing, or irrigation after a harvest of wheat and maize. Irrigation after the harvest of crops (wheat or maize) in Shiyang River Basin is still typical; the purpose of it is to furrow the soil. There is a long fallow season after the soil furrow, especially for wheat, and so because the water in the soil is evaporated into the air, it produces no biological outputs. Thus, the irrigation after the harvest is unnecessary. Shallow harrow and grinding of the soil can be applied after the harvest, as it will keep soil water moisture and reduce lost of water in the soil. No furrow will reduce water volume for winter irrigation, it is a practical and effective water saving technique, and it is increasingly popular around the world.

No furrow is suitable for semi-arid and arid areas in China, especially areas where desertification is serious; it can keep water and protect soil from wind erosion. This technique is being promoted in China with great efforts.

Third, another approach is to use early spring irrigation instead of winter irrigation. For example, spring maize can be planted in Mid April.

If the above techniques are implemented jointly, water volume of irrigations will be reduced greatly. Even 100m3 of irrigation volume can be saved per *mu*.

2.3 Land preparation

Land preparation is an on-farm measure which farmers are very familiar with, and that has been applied for a long period. On-farm water saving techniques poses new challenges to traditional techniques with a long history. Water saving techniques related to land preparation include: land levelling, change plot size, no-tillage, plough-harrow-grind to keep soil water moisture, water retain and storage, and etc. The purposes of the above techniques are to reduce non-beneficial losses and to keep irrigated water and rainfall.

Land levelling and changes to plot size are necessary measures to ensure even spread of water in plots. If land is not level, irrigation volume and frequency have to be increased, which does not save water.

At present, plot size in groundwater irrigation district in Liangzhou District is typically 1-3*mu*. Plot size in the surface water irrigation district is typically 7-8*mu*, which is difficult to make water spread evenly in the plot. Based on experiment data from local irrigation experiment stations, it is suggested that plot size should be smaller than 0.5*mu*. At this size, it is easy to control irrigation and is favourable to do land levelling.

Regarding land preparation techniques, lasers are typically used for land levelling in other countries. The theory is similar with a carpenter sawing wood according to an aiming line. In agriculture practices, farmers could use their own ways to do land levelling as long as the land can be levelled.

Land levelling and changing plot size could not only make water spread evenly in the plot, but it also could reduce water used for every round of irrigation. It is necessary to use rational allocation irrigation volume during crops growing period under limited water rights and irrigation quota. Based on experiments done by WRDMAP with Production Group 4 of Wutong village in Yongchang irrigation district of Liangzhou District, Gansu Province—when plot size change from 1*mu* to 0.3*mu*, a target irrigation water volume of 60m3/*mu* is achievable.

Machines for land avourabl with laser

2.4 Furrow irrigation and ridge planting

Furrow irrigation and ridge planting are included in interlacing irrigation. Its advantages are that farmland irrigation area is reduced and so water volume used per irrigation is also reduced. Soil evaporation is reduced as well because the area of moisture soil becomes narrower, so water is saved. Under the background of water rights allocation system is applied in the SRB, and there is not enough water for irrigation, this technique is deserved to be promoted with great efforts.

Ridge planting is a relatively mature technique. In general, ridge width is 50cm, 3 lines of wheat (or 2 lines of maize) can be planted on the top, ridge height is 15cm, ditch width is 25cm. Applications of the technique in various areas can vary with local situation, for example, widespread intercropping of wheat and maize in SRB, with ridge width unchanged, ditch width can be increased to some extent, to plant maize. The essential part of this technique is to change flood irrigation into irrigation in small ditches, letting water infiltrate into soil under the ridges. 30-40% irrigation water is saved with this technique applied. Scattering of fertilizer application is changed into concentrated application within ditches, and so 10-15% fertilizer is saved. Ridge planting is favourable to make the most of border row of one season crops and intercropping crops, taking ridge planting of wheat for example, this technique increases number of grains and TGWT, Typically yield per *mu* is increased by around 10%.

Various ridge-making machines are also needed to support this process, such as the newly-invented ridge-making and planting machine for wheat, ridge making, planting and fertilizer application are undertaken at one stroke, which reduces procedures and labour input for on-farm cultivation. It is very popular among farmers.

Furrow irrigation has already been applied in SRB and HeiHe River Basin; its effects are quite good.

Furrow irrigation for wheat

2.5 Deficit irrigation

Irrigation quota is 410m3/*mu*/year. This is not a problem for wheat of which the growing period is short, but if for intercropping of wheat and maize, how can one ensure that crops grow year round?

Drought resistance of crops at different growing stages are different. Resulting problems are relatively small if irrigation comes several days later at certain stages. What are these stages? Based on many experiments, it is shown that during the wheat and maize growing period, appropriate water shortages at a later stage of grain filling will not result in a great reduction in yield. “Critical stages” of crop water requirements are silking, flowering, and early stage grain filling. During these stages water should be available in the soil, according to the saying: “Without irrigation during blooming, yield will reduce by half”. Deficit irrigation has a broad application prospect in areas where water scarcity is serious. If irrigation water volume can not meet crop water requirements, deficit irrigation can be applied, such as irrigation to protect seedlings, irrigation for flowering and for grain filling are ensured to happen.

Deficit irrigation just uses water when it is needed most, but there are relatively greater difficulties in its applications. This technique can be tried when irrigation volume can not meet crop water requirements.

2.6 Greenhouses

Greenhouses are mainly used for high-value crops, such as vegetables, fruits and melons, edible mushrooms, and even flowers. Greenhouses can save water, especially when they are equipped with pipe irrigation and drip irrigation facilities, much more water will be saved. If greenhouses are combined with fields, part of water saved in greenhouses can be used in fields.

Costs of greenhouses construction are various; governments of various places provide certain subsidies, but there are great differences among these subsidies. In general, greenhouses of relative good quality, with heat insulation material, thickened cement, steel tube frames with automatic rolling blind, and a relatively good gatehouse, plastic film and straw sheet are not included, the cost of the greenhouse is about 80-90 thousand RMB/*mu*. If rammed earth wall is applied, reinforcing steel bars and automatic rolling blind, and with gatehouse, the cost is about 45-55 thousand RMB/*mu*, The most simple greenhouses, with earth wall and cement columns, bamboo/wood frames, at least, the cost is 15 thousand RMB/*mu*.

Besides the increase in investment, greenhouses have a higher demand for cultivation techniques and labour input. The higher value the products have, the bigger the market risks are. It is better to learn from farmers who have experience in greenhouse cultivations in neighbouring villages or areas, and consult related staff from agricultural departments before they apply this technique. And they should often pay more attention to market information.

Greenhouses, despite being a higher investment, can actually save water.

2.7 Straw mulching

With social-economic development and improvements in people's living standards, straw is no longer used for fuel in many areas in China. In many places where straw can not be used, straw is burned, which results in environment pollution, and makes valuable biological energy source lost. Based on many experiments, it is shown that straw mulching can reduce one-third to one-half of soil evaporation, meanwhile it can also improve soil fertility and reduce applications of fertilizer. It is easy to do wheat straw mulching, but is relatively difficult to do maize straw mulching. Recently many special studies have investigated straw mulching, and many straw crushing machines have been produced. There is even a special machine for maize straw carding and mulching, which eliminates the difficulties in maize straw mulching.

Wheat and maize straw mulching in Yongchang County in Gansu Province

Support machines are necessary for straw mulching. In North China, the cost of using a maize straw crusher is 50RMB/*mu*; if rotary tillage is included, generally the cost is 80RMB/*mu*. Under the background of rural labour transfer to urban areas in China, machine application is essential; farmers of good economic conditions can purchase a machine themselves and use it to help others achieve economic returns. Governments can also provide certain subsidies to farmers who take the lead in purchasing the machine.

Advantages of straw mulching are to save water and fertilizer, and to save cost of straw treatments.

2.8 Plastic mulching

In the past, plastic mulching has been used only for high value crops, such as vegetables and fruits, now is also used for cotton, maize, and etc. In North China, such as in Xinjiang Province, Shiyang River Basin, and Daling River Basin, this is widely used and has become an important measure for water saving and yield increase of agriculture in arid, semi-arid areas. In SRB, plastic mulching application for maize and cotton has been accepted by local farmers.

Advantages

- **Temperature of the soil is increased:** plastic mulching can increase temperature of the soil significantly, in spring temperature of 5-10cm soil layer can be increased by 2-4℃ with plastic mulching, which quickens growing process of crops, increases yield.
- **Soil water moisture keeping, yield increases and weeds damage reduction:** plastic mulching controls evaporation of the soil, quite high moisture are kept in 20cm soil layer at the surface, and over 20% ET during crop growing period is reduced. Effective accumulated temperature of crops growing in Liangzhou District is lower, so maize and cotton cultivation with plastic mulching can increase yield significantly and reduce weeds and pests in the fields.

Maize with plastic mulching

Farmland near Qilian Mountain has insufficient thermal resources, very little rainfall in early spring, and poor soil water moisture, therefore its yield of maize is low. Maize cultivation with plastic mulching can increase the temperature of maize root area and increase yield. Based on investigations undertaken in Heping township in Liangzhou District, yield of maize with plastic mulching can increase by over 300kg/*mu*— water is saved and quite good economic returns is got. However, attention must be paid to protect plastic film. It is better to remove the plastic film next spring, to reduce water losses of soil in winter.

Cotton cultivation with plastic mulching

Effective accumulated temperature of the soil is increased with plastic mulching, which enlarge planting area of cotton, and increase the yield. For example, in Minqin County in Gansu Province, the yield of cotton with plastic mulching is 10-40kg/*mu* more than that of cotton without it, which has been accepted by local farmers.

Although plastic mulching requires intensive labour inputs, this problem could be solved by cooperation and collaboration.

2.9 Irrigation water saving with pipe distribution system

Low-pressure pipelines

Irrigation using low-pressure pipes has the following advantages:

- **Water saving:** pipes are used to distribute water. Convey losses are generally less than 5%, and irrigation intensity increases, which will reduce water volume used per irrigation, compared to earth canals, 30% water can be saved.
- **Time and efforts saving and yield increases:** Shorter time is consumed with pipe distribution when fields are irrigated, and no water is lost while being conveyed. The number of plots that can be irrigated per day increases by 30%, while labour input reduces by more than one third.
- **Reduction in land occupation.** Buried pipes can save land occupied by canals on the surface, which can save 2%.

Two patterns which are used widely in agriculture production are pipe and earth ditches (especially), and low pressure pipes and surface hoses. Inputs for low pressure pipes, the first pattern is about 130-150RMB/*mu*, the other one is about 180-200RMB/*mu*, valid period is 10 years, with an annual average input 13-20 RMB/*mu*. Currently, governments are investing 90% for low pressure pipes, individuals input labour and 10% material cost.

Irrigation with hose distribution

Irrigation with hose distribution is very convenient, economical, and easy to be transported, which is most suitable for slopes and plains where are suffered from water scarcity.

While pipes and earth ditches are used where there are no low pressure pipes in place, hoses are used for primary and secondary canals when water scarcity is very serious. It can improve irrigation efficiency and increase irrigated area, with lower input. Market prices of hoses currently is 1 RMB/m, valid period is 3-5 years.

Sprinkler irrigation

Watermelon cultivation with infiltration irrigation

Infiltration irrigation

Micro-irrigation in the earth sends water into the soil through underneath pipes which can infiltrate water, then capillaries in the soil will absorb this water and transport it to the soil around the pipes, to be absorbed and used by plants. No surface wetness will take place during the irrigation, so it can reduce unbeneficial evaporation of soil water to the most, can saving much water, but now its applications are quite small, especially for field crops.

Dripping irrigation underneath plastic mulching for cotton

2.10 Dripping irrigation

Dripping irrigation includes movable and fixed systems, which only use water 10-20m3/*mu* per irrigation. Compared to traditional irrigation, it just use 40-70% of water used during one growing season. The costs for the dripping irrigation system are relatively high, so it is mainly used in greenhouses, orchards, and for cotton, maize, of which plants are bigger.

Generally a dripping irrigation system includes a filtering tank, fertilizer tank (dispensable) and drip tapes. With the localization level of dripping irrigation system increasing, the prices becomes lower and lower. Generally, costs of a first pivot is about 450 RMB/*mu*, on-farm drip tape is about 350 RMB/*mu*, and valid period of first pivot is 10 years, drip tapes 4-5 years, so input/year is only about 150 RMB/*mu*.

Dripping irrigation underneath plastic mulching

A combination of plastic mulching with dripping irrigation is mainly applied for cotton production in Northwest China, with a strong effect on yield increases and water saving. For example, in Xinjiang Province where this irrigation is applied, on the one hand, production costs is recovered, on the other hand, economic returns/*mu* is increased by over 180RMB.

Document Reference Sheet

Glossary:

Mu	Chinese measurement of area, equivalent to 666.66 square meters
SRB	Shiyang River Basin in Gansu Province
WMS	Water Management Station
WUA	Water users' Association

Bibliography:

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