CHINA'S XINJIANG FILM-MULCHED DRIP IRRIGATION TECHNOLOGY: A STANDARD-BASED ASSESSMENT OF WATER AND ENERGY SAVING

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Abstract*: Film-mulched drip irrigation, widely associated with the irrigated oases of Xinjiang, China, is more than the placement of drip tape under plastic film. It is an integrated water-saving system that combines local water storage, pumping and control, filtration, fertigation, low-pressure laterals, weather and soil monitoring, and root-zone moisture management. This paper evaluates the technology using a literature-based IMRAD approach, standard engineering criteria, field photographs of typical components, and an illustrative hydraulic-energy calculation for a pumped irrigation unit. The analysis shows that the main energy benefit comes from two linked mechanisms: reducing the seasonal water volume and keeping the operating pressure only as high as needed for uniform emitter discharge. In the demonstration calculation, a film-mulched low-pressure drip option required about 191 kWh ha-1 season-1 for pressure lift, compared with about 807 kWh ha-1 season-1 for a high-pressure sprinkler scenario. Agronomically, the technology improves the soil hydrothermal environment, reduces nonproductive evaporation, supports precise fertigation, and can increase water productivity. Its sustainability, however, depends on filtration maintenance, pressure uniformity,* *salinity leaching, fertilizer balance, and responsible management of plastic-film residues.*

Keywords: *film-mulched drip irrigation; Xinjiang; under-film drip tape; energy saving; water productivity; fertigation; soil salinity.*

1. Introduction

Water scarcity is the central technical constraint of irrigated agriculture in arid and semi-arid regions. Xinjiang's oasis agriculture has responded to this constraint by developing film-mulched drip irrigation (MDI), in which drip tapes are placed under plastic or degradable mulch and irrigation is applied frequently in small doses. The system is now regarded as one of the strongest examples of integrated water-saving irrigation in cotton production because it combines crop-water scheduling, local pressure control, fertigation, and soil surface management in one package [1-4].

The agronomic principle is simple but powerful. Plastic film reduces direct soil evaporation, moderates the temperature of the seedbed, suppresses weeds, and helps maintain a moist root zone. Drip irrigation supplies water and fertilizer near the active roots, reducing wetting of non-crop soil and allowing the operator to match irrigation to crop demand. Field studies in the Tarim Basin and other Xinjiang cotton areas have shown that suitable irrigation regimes can maintain high cotton yield and water productivity, provided that salt movement is controlled through correct scheduling and, when necessary, post-season leaching [6,7,16].

Research has also moved beyond the question of whether MDI saves water. Studies now focus on how much water should be applied, which soil moisture threshold should trigger irrigation, and how water and nitrogen should be coupled. Li et al. reported that optimized irrigation and nitrogen combinations can keep yield, water-use efficiency, nitrogen-use efficiency, and economic benefit near their maximum values in northern Xinjiang [8]. He et al. showed that soil-moisture regulation under MDI strongly affects soil salt distribution and cotton growth in southern Xinjiang [9]. Root studies further indicate that the wet and warm upper soil layer created by film and drip irrigation can stimulate fine-root development and improve water uptake [10].

At the same time, the technology should not be described as problem-free. Long-term MDI can redistribute salts in ways that are beneficial during the growing season but risky if drainage and leaching are ignored [12,16]. Residual plastic-film fragments are another concern because they can damage soil structure, alter infiltration, and reduce crop growth when they accumulate [14,15]. Recent work on biodegradable and sprayable degradable films is therefore important for maintaining the yield advantages of MDI while reducing plastic pollution [18]. A sustainable design must treat water saving, energy saving, salinity control, and residue management as one engineering problem [11,13].

From the hydraulic point of view, MDI is a low-pressure microirrigation system. Its performance depends on emitter quality, pressure uniformity, filtration, flow measurement, and regular flushing. ISO 9261 defines mechanical and functional requirements and test methods for emitters and emitting pipe, while ASABE EP405.1 sets engineering practice recommendations for microirrigation design and installation [3,4]. FAO guidelines and classic drip-irrigation maintenance literature also emphasize that evapotranspiration-based scheduling, filtration, water quality control, and preventive maintenance are essential for avoiding clogging and uneven water application [1,2,5]. Therefore, the objective of this paper is to assess Xinjiang’s under-film drip technology as a standard-based water- and energy-saving system and to identify the design conditions required for its safe application in water-scarce farming regions.

2. Materials and Methods

The paper was prepared as a technical research-and-review study. The evidence base consisted of peer-reviewed studies on Xinjiang film-mulched drip irrigation, international guidance on crop-water calculation and pressurized irrigation, and field photographs representing the main equipment groups used in practical irrigation units. The analysis followed three steps: first, the main components of an under-film drip system were identified; second, design requirements were organized according to microirrigation standards and field-operating practice; and third, an illustrative energy calculation was made to show how pressure and water volume affect pumping energy.

Crop-water demand was interpreted using the FAO-56 approach, where crop evapotranspiration is estimated as ETc = Kc x ETo. In an operational farm schedule, this value is adjusted by effective rainfall, soil-water storage, leaching requirement, application efficiency, and the irrigation interval. In MDI, irrigation depth is normally divided into frequent small applications so that the wetting bulb remains under the film and near the root zone. This reduces evaporation losses but also requires good pressure control and emitter uniformity.

The hydraulic-energy calculation used the standard pump relation E = V x 0.002725 x H / eta, where E is energy in kWh, V is seasonal pumped water volume in cubic metres per hectare, H is total dynamic head in metres, and eta is pump-motor efficiency. The coefficient 0.002725 converts the energy needed to lift one cubic metre of water by one metre into kWh. A pump-motor efficiency of 0.65 was used as a conservative planning value. The calculation is illustrative; it does not replace a site-specific design that includes well depth, elevation, pipe friction, filter head loss, actual motor efficiency, and pump curve selection.

For the technical assessment, the system was divided into seven interacting units: water source and storage, pumping/control head, filtration and fertigation, main/submain pipelines, drip tape laterals, mulch and planting geometry, and monitoring/maintenance. The photographs supplied for this article were interpreted as field examples of the monitoring station, automatic control unit, pump with pressure measurement, and lined water-storage pond. These components are discussed in the Results and Discussion section because their value is mainly operational: they reduce unnecessary run-time, stabilize pressure, and help avoid over-irrigation.

3. Results and Discussion

3.1. System configuration observed in field components

Figure 1 shows the practical equipment chain that makes under-film drip irrigation efficient. The monitoring station supports irrigation scheduling by recording weather and, when connected to soil sensors, root-zone moisture conditions. The automatic control unit starts and stops pumping, protects the system, and can be integrated with fertigation. The pump and pressure gauge are critical because the energy cost of pressurized irrigation rises directly with head. The lined storage pond buffers canal or well water, promotes sedimentation before filtration, and gives the operator flexibility to irrigate at the most suitable time rather than only when water arrives. Together these elements reduce energy use not through a single device, but by shortening pump operating hours, avoiding excessive pressure, and preventing re-irrigation caused by poor uniformity.

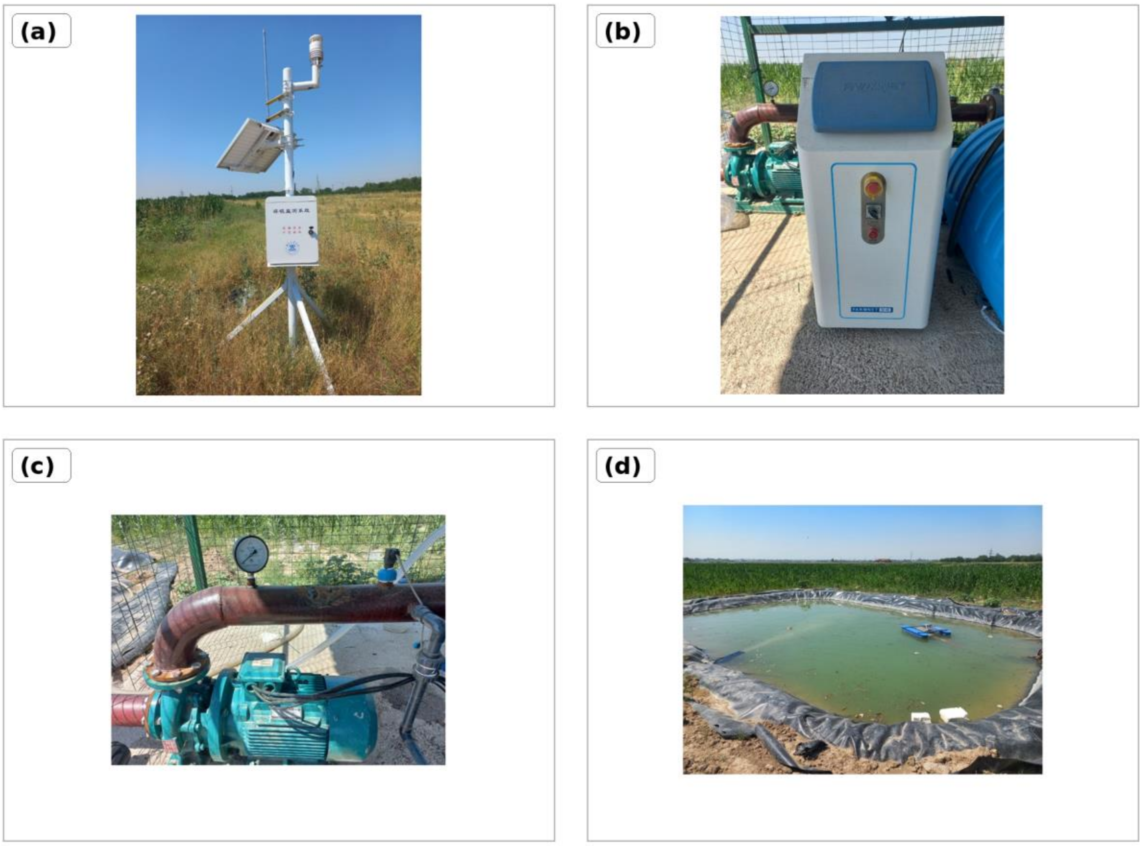

Figure 1. Field components of an energy-efficient film-mulched drip irrigation unit: (a) solar environmental monitoring station, (b) automatic

pump/control unit, (c) centrifugal pump with pressure gauge, and (d) lined storage pond. Photographs supplied by the author.

3.2. Standard-based technical requirements

A film-mulched drip irrigation system can save water only when the hydraulic network is correctly designed and maintained. A poorly filtered, leaking, or over-pressurized drip system can waste both water and energy. Table 1 summarizes standard-based requirements that should be checked before field installation and during seasonal operation. The values are practical design ranges; final selection must be adjusted to water quality, crop spacing, soil texture, field slope, and the manufacturer's emitter data.

Component	**Recommended technical requirement**	**Purpose in the system**
Water source and pond	Use lined storage or settling before pumping; test EC, pH, suspended solids and biological load.	Reduces sediment load, stabilizes water supply and supports salinity decisions.
Pump and control head	Select pump from the required flow and total dynamic head; use pressure gauges before and after filtration; avoid unnecessary throttling.	Maintains uniform pressure while reducing wasted electrical energy.
Filtration	Use screen, disc or media filtration according to water quality and emitter passage; backwash/clean when differential pressure rises.	Prevents emitter clogging and protects application uniformity.
Emitters and drip tape	Use tested emitters/emitting pipe conforming to ISO 9261; typical cotton tapes are 16 mm with 20-30 cm emitter spacing.	Ensures predictable discharge and even wetting under the film.

Operating pressure	Keep lateral-inlet pressure within manufacturer range; low-pressure tapes commonly operate near 50-100 kPa.	Reduces pumping head without sacrificing uniformity.
Fertigation unit	Inject only soluble fertilizers through a calibrated Venturi or dosing pump; flush lines after fertigation.	Improves nutrient-use efficiency and reduces salt/fertilizer hot spots.
Monitoring and maintenance	Record flow, pressure, kWh, irrigation time, soil moisture and soil EC; flush submains/laterals routinely.	Turns drip irrigation from a hardware installation into a controlled management system.

Table 1. Technical requirements for film-mulched drip irrigation based on microirrigation standards and field operating practice [2-5].

3.3. Energy-saving mechanism

Energy saving in MDI is a combined result of agronomy and hydraulics. Agronomically, the film reduces evaporation from the soil surface, so the required irrigation volume can be lower than in uncovered or less controlled systems. Hydraulically, drip tape operates at a lower pressure than sprinkler irrigation, and a well-designed network avoids excess head loss. Figure 2 illustrates the operational logic: water is stored and settled, pumped through filtration/fertigation, delivered at low pressure to under-film drip tape, and adjusted by monitoring feedback. This is why a pressure gauge and controller are not minor accessories; they are the instruments that prevent the operator from pumping more water or pressure than the crop needs.

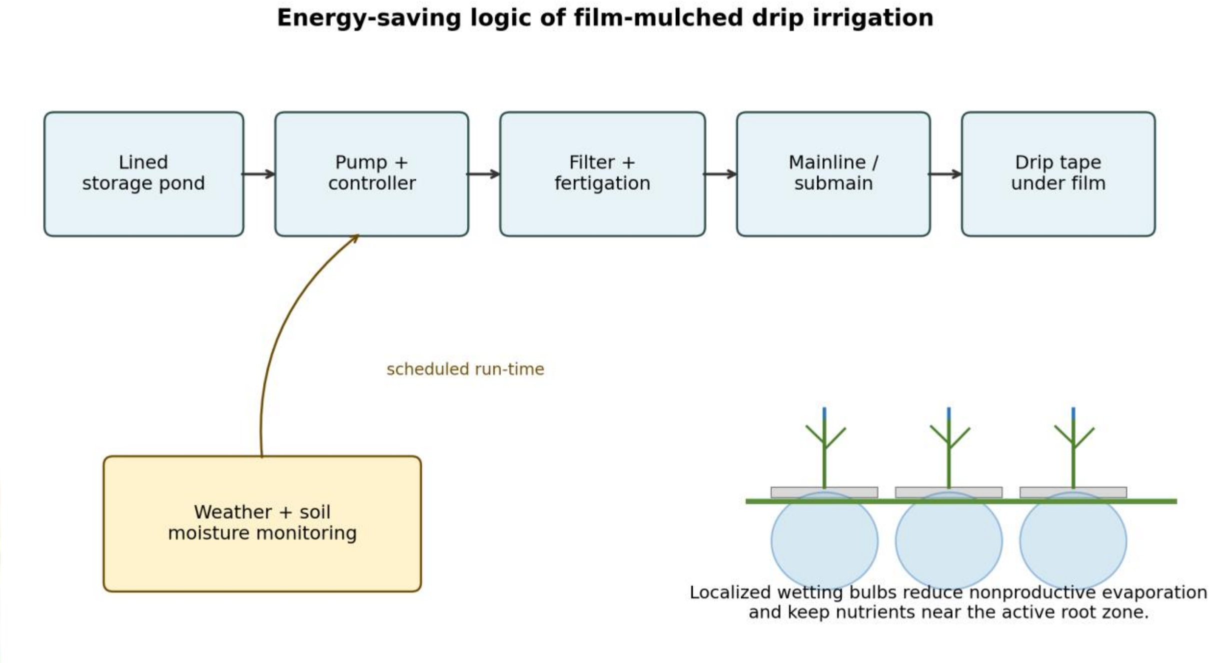

Figure 2. Schematic energy-saving logic of Xinjiang-style film-mulched drip irrigation.

The illustrative calculation in Table 2 and Figure 3 compares three pumped scenarios. The values are not a field measurement; they are a transparent planning calculation using the same pump-efficiency assumption. The result is clear: reducing seasonal water volume from 5500 to 3800 m3 ha-1 and operating at 12 m head instead of 35 m head lowers pressure-lift energy from about 807 to 191 kWh ha-1 season-1. The reduction would be smaller on fields with large elevation lift or poor pump efficiency, and larger where old high-pressure equipment is replaced by well-matched low-pressure drip equipment.

Irrigation option	**Seasonal volume (m3 ha-1)**	**Head (m)**	**Energy (kWh ha-1)**	**Relative energy**
High-pressure sprinkler	5500	35	807	100%
Drip without film	5000	20	419	52%
Film-mulched low-pressure drip	3800	12	191	24%

Table 2. Illustrative seasonal pressure-lift energy for a pumped 1 ha irrigation unit, assuming pump-motor efficiency eta = 0.65.

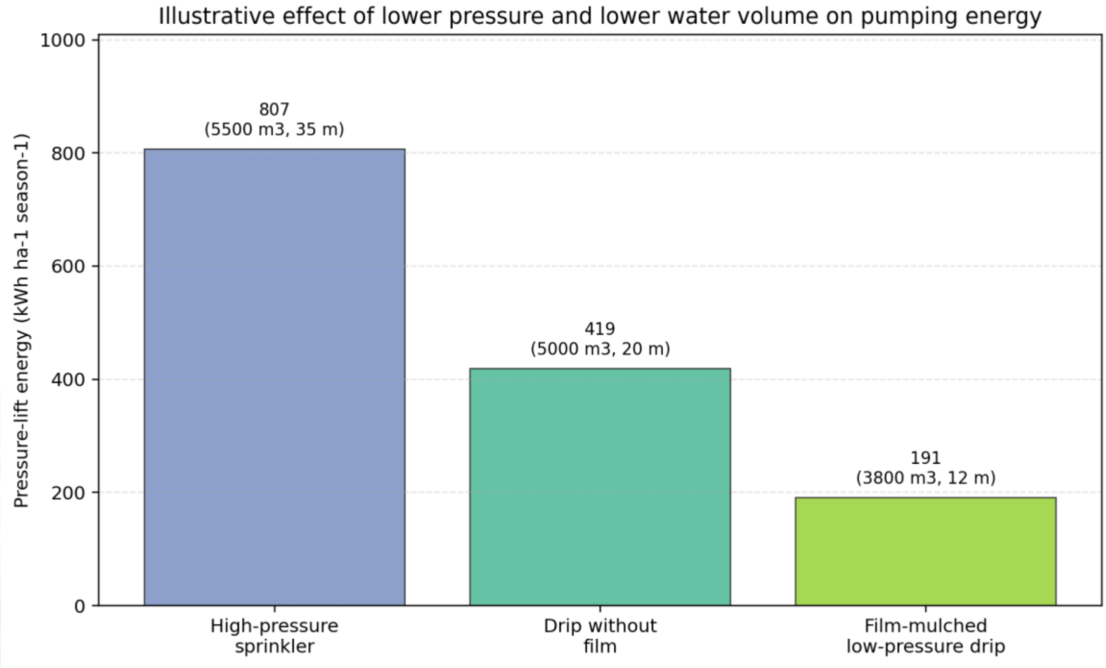

Figure 3. Calculated energy comparison for three pressurized irrigation options. Actual values depend on lift, pipe losses, filter head loss and pump selection.

3.4. Agronomic performance, salinity and sustainability

The agronomic value of MDI is strongest when water, fertilizer, and salt are managed together. Published Xinjiang experiments report that irrigation amount and nitrogen rate influence not only yield, but also water-use efficiency, nitrogen-use efficiency and economic return [8]. Moisture-threshold studies show that very high irrigation lower limits can increase water use without proportional yield gain, while very low limits can reduce boll development and fiber quality [9]. Therefore, the practical target is not maximum irrigation, but stable moisture in the active root zone during sensitive growth stages, especially flowering and boll formation.

Salinity is the main long-term risk. During the season, drip irrigation often pushes salts away from the emitter and keeps the wet bulb relatively favorable for roots. After harvest, however, salts may accumulate near the soil surface or between mulch strips if leaching and drainage are insufficient [12,16]. This means that water-saving irrigation must still reserve enough water for salt control where water or groundwater salinity is high. Periodic soil EC monitoring, post-season freshwater leaching, drainage maintenance, and differential irrigation quotas for saline fields are necessary technical conditions, not optional additions.

The second sustainability issue is plastic residue. Polyethylene film contributes to early growth and water saving, but incomplete recovery can leave fragments in soil. Residual film can interfere with infiltration, root growth and soil structure, while long-term accumulation weakens the environmental case for the technology [14,15]. Biodegradable or sprayable degradable films are promising, but they must be judged on field degradation, crop response, cost, and local climatic conditions rather than on the word 'degradable' alone [18]. For Central Asian adoption, the most reliable approach is to combine film recovery rules, farmer training, and gradual testing of alternative mulches.

Management target	**Field indicator**	**Recommended action**
Uniform water application	Flow rate, lateral pressure, visual wetting pattern	Check pressure at head and tail; repair leaks; flush laterals before fertigation and at season end.
Clogging prevention	Filter differential pressure, emitter discharge variation	Backwash filters, settle pond water, and use chemical treatment only after water-quality diagnosis.
Energy control	kWh per m3, pump run-time, pressure above target	Use suitable pump curve, avoid over-pressure, irrigate by ET/soil moisture and night-time tariffs where available.
Salinity control	Soil EC in 0-60 cm layer and between film strips	Apply planned leaching, maintain drainage and adapt quota by soil salinity class.

Fertigation efficiency	Fertilizer dose, irrigation EC/pH, leaf/crop response	Split nitrogen through the season, keep fertilizers soluble and flush clean water after injection.
Film sustainability	Recovered film mass, visible residues in soil	Collect film after harvest; test biodegradable or sprayable films in small plots before scaling.

Table 3. Practical operating checklist for maintaining the water, energy and sustainability benefits of MDI.

4. Conclusions

Xinjiang's film-mulched drip irrigation technology should be understood as an integrated system: drip tape, mulch, pumping, filtration, fertigation, field storage, and monitoring work together. The technology saves water by concentrating moisture in the root zone and saves energy when lower water volume is combined with low operating pressure and good pump selection.

The demonstration calculation showed that a low-pressure film-mulched drip scenario can require roughly one quarter of the pressure-lift energy of a high-pressure sprinkler scenario under the stated assumptions. This supports the practical observation that monitoring units, automatic controllers, pressure gauges and lined ponds are energy-saving tools because they prevent unnecessary pump operation and over-pressure.

The strongest agronomic benefits occur when irrigation scheduling is tied to ET, soil moisture, crop growth stage and nitrogen management. The technology is not sustainable if salinity, clogged emitters or residual plastic film are ignored. Therefore, standard-based design, filter maintenance, soil EC monitoring, drainage/leaching management and film recovery must be part of every project.

For Uzbekistan and other arid irrigated regions, the Xinjiang experience is useful because it shows that water-saving irrigation is a management culture as much as a hardware package. Pilot farms should start with measured water and energy accounting, compare pressure and flow before and after modernization, and train operators to make decisions from gauges, sensors and crop conditions rather than from fixed calendar irrigation alone.

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