Innovative Irrigation Practices in Arid Regions

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1. INTRODUCTION

Agriculture currently uses about 70% of the total water withdraw, mainly for irrigation. Although irrigation has been practiced for millennia, most irrigated lands were introduced in the 20th century. The intensive irrigation could provide for the growth of irrigated areas and guarantee increased food production. In the 1980s, the global rate of increase in irrigated areas slowed considerably, mainly due to very high cost of irrigation system construction, soil salinization, the depletion of irrigation water-supplying sources, and the problems of environmental protection. However, as the population is growing at a rapid rate, irrigation is being given an important role in increasing land use and cattle-breeding efficiency. Thus, irrigated farming is expected to expand rapidly in the future with subsequent increase of water use for irrigation.

Irrigation is not sustainable if water supplies are not reliable. Especially in areas of water scarcity the major need for development of irrigation is to minimize water use. Effort is needed to find economic crops using minimal water, to use application methods that minimize loss of water by evaporation from the soil or percolation of water beyond the depth of root zone and to minimize losses of water from storage or delivery systems. Nowadays, during a period of dramatic changes and water resources uncertainty there is a need to provide some support and encouragement to farmers to move from their traditional high-water demand cropping and irrigation practices to modern, reduced demand systems and technologies.

Under water demand management most attention has been given to irrigation scheduling (when to irrigate and how much water to apply) giving minor role to irrigation methods (how to apply the water in the field). Many parameters like crop growth stage and its sensitivity to water stress, climatic conditions and water availability in the soil determine when to irrigate or the so-called irrigation frequency. However, this frequency depends upon the irrigation method and therefore, both irrigation scheduling and the irrigation method are inter-related.

2. SURFACE IRRIGATION METHODS

Surface irrigation methods are the traditional methods used from ancient times until nowadays and include basin, furrow and border irrigation. In basin irrigation the water is applied to leveled fields bounded by dikes, the so-called basins. The shape and size of the basin depends on crop type. For vegetables or row crops the basins are often furrowed with the crops being planted on raised beds or ridges, while for tree crops the basin has raised beds around the tree trunk to prevent disease development. Large irrigations can be given when soil infiltration rates are moderate to low and soil water holding capacity is high. Irrigation depths usually exceed 50 mm and a relatively high inflow rate (> 2 l/s per meter width) is required.

In furrow irrigation water is applied to small and regular channels, called furrows, and this method is usually applied to row crops. Furrows must have a mild slope and inflow discharges must be such that water movement is not too fast, nor too slow. Efficient furrow irrigation nearly always requires irrigation times longer than advance times. Irrigation depths are usually >20 mm. In border irrigation water is applied to sort or long strips of land, diked on both sides and open at the downstream end. Water is applied at the upstream end and moves as a sheet down the border. The method is best adapted to areas with slow slopes, moderate infiltration rates and large water supply rates. The irrigation depths range from 20 to 50 mm.

The main disadvantages of surface irrigation methods are the low irrigation efficiencies (50-60%), the requirement of large discharges per unit area and the high labour cost, while they are not able to apply small irrigation depths, so that they are not suitable for supplemental irrigation. Improvements in surface irrigation methods aiming at reducing volumes and increasing the water productivity include land leveling and reduced widths and/or shorten lengths while for the on farm water distribution improvements include gated pipes and lay flat pipes, buried pipes for basin and borders, lined–on farm distribution canals, good construction of on-farm earth canals, easier control of discharges and control of seepage.

3. SPRINKLER IRRIGATION

Sprinkler irrigation developed mainly after 1950, with the introduction of light-weight aluminum pipes. Sprinkler irrigation uses specific devices (sprinklers) to apply water in the field. If it is well designed the irrigation efficiency can reach up to 85%. However, sprinkler irrigation systems have high-energy consumption, high investment cost, while technical support is required. The main sprinkler systems in use are:

• *Set systems*: the sprinklers irrigate in a fixed position and can apply small to large water depths. The have high cost and are best adapted to small farms.

• *Traveling guns*: a high-pressure sprinkler continuously travels while irrigating a rectangular field. They have high-energy requirement, high evaporation losses in arid regions and are not suitable for applying very small or large depths, or to irrigate heavy soils and sensitive crops.

• *Continuous move laterals*: the sprinklers operate while the lateral is moving in either a circular or a straight line. The laterals are equipped with sprinklers or sprayers. This system is suitable to apply small and frequent irrigation in very large farms.

Improvements in sprinkler irrigation systems aimed to reduce the volumes of water applied and increase water productivity include the adoption or correction of sprinkler spacing, the design for pressure variation not exceeding 20% of the average sprinkler pressure, the use of pressure regulators in sloping fields, the monitoring and adjustment pressure equipment, application of irrigation during no windy periods, adoption of smaller spacing and large sprinkler drops and application rates in windy areas, the adoption of application rates smaller than the infiltration rate of the soil and careful system maintenance.

4. LOCALIZED IRRIGATION METHODS

Localized irrigation is widely recognized as one of the most efficient methods of watering crops. Localized irrigation systems (trickle or drip irrigation, micro-sprayers) apply the water to individual plants by means of plastic pipes, usually laid on the ground surface. With drip irrigation water is slowly applied through small emitter openings from plastic pipes with discharge rate ≤ 12 l/h. With micro-sprayer (micro-sprinkler) irrigation water is sprayed over the part of the soil surface occupied by the plant with a discharge rate of 12 to 200 l/h. The aims of localized irrigation are mainly the application of water directly into the root system under conditions of high availability, the avoidance of water losses during or after water application and the reduction of the water application cost (less labour). The main characteristics are:

a. *Low rate of water application* (discharge rate < 200 l/h for mini sprinklers, <12 l/h for drippers and an application rate 1-5 mm/h)

b. *Partial soil wetting.* Wetted soil is a portion of the soil volume available to the roots, 30-40% for tree crops, and 50-80% for vegetables.

c. *Low doses, high frequency, long duration of irrigation.* Doses 1/3 - 1/10 of those used for surface methods. High frequency (usually one irrigation per 1-7 days)

d. *High soil water availability*. Slow and frequent irrigations ensure that water content in the soil remains high and fairly constant and the soil water tension remains low (1/3 of Atm) resulting in high water availability to the plant.

Studies in countries as diverse as India, Israel, Spain and United States have consistently shown that drip irrigation reduces water use by 30 to 70% and raises crop yields by 20 to 90%. The advantages of localized irrigation are: a) Efficient water use (efficiency up to 95%) b) Reduced labour cost (can be highly automated) c) Easy and efficient application of fertilizer and other chemicals d) Reduced salinity hazards e) Better phytosanitary conditions f) Simultaneous performance of other cultural practices g) Can be used on uneven or sloping areas and h) Valorization of small water discharges. Drip irrigation's combination of water savings and higher yields typically increases at least by 50% the water use efficiency, yield per unit water (Tab. 1), and makes it a leading technology in the global challenge of boosting crop production in the face of serious water constrains. Although the area of localized irrigation has expanded 50-fold over the last two decades, it still represents less than 2 percent of the world's irrigated area. The main barriers to its expansion are the high investment cost, ranging from 1,500 to 2,500 € per hectare, and the high sensitivity to clogging.

Table 1. Irrigation water, yield and WUE in kiwi irrigated with different systems

Irrigation system	Water used* (mm)	Yield (kg/tree)	WUE (kg/mm)
Drip	340	33.2 a	4.00 a
Micro-sprinkler	477	30.9 a	2.65 b
Overhead sprinkler	782	34.6 a	1.81 c

* Average of 10 years

The main components of a drip irrigation system are: i) The pressure source (collective pressurized network, pumping station or elevated water storage tank) ii) The control head (different kinds of filters, fertilizer tank, pressure regulators, valves, water meters, automation devices) iii) The pipelines (main pipe, manifolds and laterals) and iv) The emitters (drippers –'on line', in line', self-cleaning or auto-regulated, mini-sprayers – stable or rotating). The main components and layout of a drip irrigation system is given in Figure 1.

Improvements in localized irrigation systems aiming to reduce the volumes of water applied and increase the water productivity include the use of a single drip line for a double row crop, the use of micro-sprayers in high infiltration soils, the adjustment of duration of water application and timing to soil and crop characteristics, the control of pressure and discharge variations, the use of appropriate filters to the water quality and the emitter characteristics used, the adoption of careful maintenance, automation, fertigation (efficient fertilizer application) and chemigation (easy control of weeds and soil born diseases).

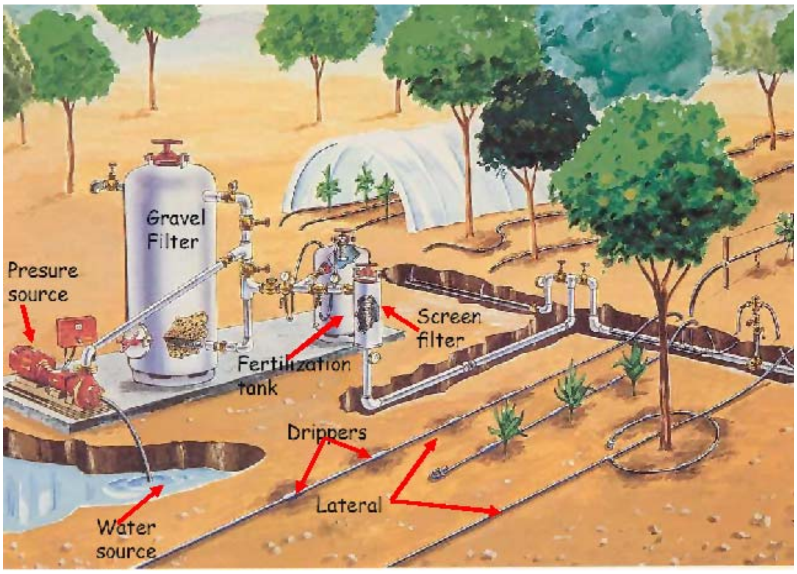

Figure 1. Main components and layout of drip irrigation system.

4.1 Filtration

Filtration is necessary for drip irrigation systems for prevention of emitter clogging, which reduces the operational capability and life of the system. The cause of clogging can be solid particles (soil, sand, solid material, etc), organic matter (vegetative parts, algae, protozoa, etc) or chemical precipitates (salts, mineral deposits, etc). The use of closed reservoirs, wells and conduits prevents the entrance of mineral and organic material in the water. When the source of irrigation water is open reservoirs, wells or canals the addition of sulfuric cooper ($CuSO_4$) at a rate of 0.5-1.5 ppm will prevent the green algae growth.

Filters that can be used in a drip system are hydrocyclons, gravel filters and screen filters. Hydrocyclone is used to remove dispersed solid material, particularly sand, from the water and is generally used in conjunction with other types of filters. The hydrocyclone is of a conical vertical body and water is entering tangentially at the top and flows down at a high rotational velocity. This pushes the solid particles against the walls of the filter gathered it at the bottom, while the clean water flows upstream into the main system. Gravel filter is used mainly to remove coarse material, as well as organic matter, microorganisms and very fine colloidal particles. The filtering material is fine gravel (1-2 mm) and coarse sand. Back washing for cleaning the filtering material can be manual or automatic. Screen filter is mainly used for retention of suspended solid material. A 140-160 mesh screen (plastic, synthetic cloth) is used as filtering material. The frame of the filter must be made of stainless steel or painted with anti-corrosive material. Many types exist in the market with manual, semi-automatic or automatic operation. The screen filter is used downstream from the gravel. The type, size and number of filters required depend on the quality of the water and the discharge in the control head.

Filters do not, as a rule, completely solve the problem of clogging, and drip systems can be expected to have certain percentage of its drippers clogged or operating poorly. However, an efficient filtration system can reduce clogging to a reasonably low level. Furthermore, filters do not overcome the problem of precipitation of calcium-carbonate or organic material. Hydrochloric or phosphoric acid is usually used to remove mineral deposits (calcium or iron precipitates). For HCl (30%), 4-6 liters per m^3 of water passing through the system and irrigation for at least 30 min, give good results. The frequency of chemical application depends on the salt content of irrigation water, but is mostly practiced at the end of the irrigation period.

4.2 Fertigation

The application of fertilizers through the irrigation system (fertigation) became a common practice in modern irrigated agriculture. Localized irrigation systems, which could be highly efficient for water application, are also suitable for fertigation. Thus, the soluble fertilizers at concentrations required by crops are applied through the irrigation system to the wetted volume of the soil. The potential advantages of fertigation are:

- Precise amount of fertilizer at the root system of the crop
- Optimum conditions for the use of fertilizer by the crop
- High fertilization efficiency
- Flexibility in timing of fertilizer application in relation to crop demand
- Environmental friendly method of fertilization (control of nutrient losses)
- Increased yield and improved quality of the products

Possible disadvantages include the non-uniform chemical distribution when irrigation design or operation are inadequate, the over-fertilization in case that irrigation is not based on actual crop requirements and the use of soluble fertilizers.

The injection of fertilizer into the irrigation water can be done either using pumping systems or pressure differential systems. With the differential pressure system a closed tank of 60-200 l capacity is used, into which the solid or liquid fertilizer is placed. The tank is connected to the main irrigation line by means of a by-pass. The gate valve generates a pressure difference between the entrance and exit of the tank, which causes the flow of water through the tank and dilutes the fertilizer. The main advantages are the simple operation and the absence of moving parts, while the main disadvantage is that the rate of fertilizer application is not constant (decreases with time).

With the pumping system a pump (electrical, hydraulic or venturi) is used to inject the fertilizer into the irrigation water. The fertilizer must be in liquid form or diluted into the tank. Advantages of the pumping system are the constant rate and the high control of dosage and timing of fertilizer application, while no special tanks are required. However, it requires a source of power and in, some cases technical assistance. The volume of fertilizer in the tank is determined from the formula V = W x A / P, where, V is the volume of the tank (l), W the amount of fertilizer required (kg/ha), A the irrigated area (ha) and P the dilution ratio of the solution (kg/l).

Table 2. Solubility of common fertilizers in water (kg fertilizer / 100L)

Fertilizer	Temperature range (^oC)		
	Cold	Medium	Hot
Ammonium chloride	30		76
Ammonium nitrate	118	195	344
MAP	23	28	42
DAP	43	58	106
Ammonium sulfate	71	76	85
Potassium chloride	28	35	43
Potassium nitrate	13	32	86
Potassium sulfate	7	11	17
Mono-K-P		33	84
D-K-P		167	
Calcium nitrate	102	341	346
Magnesium nitrate		42	58
Urea Phosphate		96	
Monocalcium-P		18	
P-acid		548	
Urea	78	119	

The solid, liquid and suspended form for of fertilizers could be used for fertigation. The fertilizers recommended for fertigation should be water soluble, not precipitating as insoluble salts by reacting with ions present in the water or other fertilizers applied simultaneously and be available in the local market at reasonable price. The solubility of common fertilizers is given in Table 2. Fertilizers partially soluble may block the system and create operational problems.

5. DEFICIT IRRIGATION PRACTICES

In the past, crop irrigation requirements did not consider limitations of the available water supplies. The irrigation scheduling was then based on covering the full crop water requirements. However, in arid and semi-arid regions increasing municipal and industrial demands for water reduce steadily water allocation to agriculture. Thus, water availability is usually limited, and certainly not enough to achieve maximum yields. Then, irrigation strategies not based on full crop water requirements should be adopted for more effective and rational use of water. Such management practices include deficit irrigation, partial root drying and subsurface irrigation.

5.1 Regulated deficit irrigation

Regulated deficit irrigation (RDI) is an optimizing strategy under which crops are allowed to sustain some degree of water deficit and yield reduction During regulated deficit irrigation the crop is exposed to certain level of water stress either during a particular period or throughout the growing season. The main objective of RDI is to increase water use efficiency (WUE) of the crop by eliminating irrigations that have little impact on yield (Tab. 3), and to improve control of vegetative growth (improve fruit size and quality.) The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under conventional irrigation practices.

Table 3. Water use and yield of 'Fino' lemon under control and RDI irrigation

Irrigation system	Applied water (mm)	Yield (kg/tree)	Number of fruit per tree
Control	690.5	208.1 a*	1839 a
RDI	485.7	199.5 a	2069 a

* Different letters within the same column indicate significant differences at a=0.05 (LSD-test)

RDI is a sustainable issue to cope with water scarcity since the allowed water deficits favour water saving, control of percolation and runoff return flows and the reduction of losses of fertilizers and agrochemicals; it provides for leaching requirements to cope with salinity and the optimization approach leads to economical viability. The adoption of deficit irrigation implies appropriate knowledge of crop ET, of crop response to water deficits including the identification of critical crop growth stages, and of the economic impact of yield reduction strategies. Therefore, appropriate deficit irrigation requires some degree of technological development to support the application of irrigation scheduling techniques.

Before implementing RDI it is necessary to know the crop yield response to water (growth stage or whole period). Crop yield response for deficit irrigation is described by the equation $Y/Y_m = 1-K_y\,[1-ET_a/ET_m]$, where Y and Y_m are the expected and maximum crop yield, ET_a and ET_m the actual and maximum ET, and K_y the crop response factor. K_y gives an indication of whether the crop is tolerant to water stress and depends on crop species, cultivar, irrigation method and growth stage. High yielding varieties are more sensitive to water stress. Crops or varieties with a short growing season are more suitable for RDI. Furthermore, in order to ensure successful RDI, it is necessary to consider the water retention capacity of the soil. In sandy soils plants undergo water stress quickly under RDI, while in deep, fine-textured soils plants have ample time to adjust to low soil water potential, and may be unaffected by low soil water content. Under RDI agronomic practices may require modifications, e.g. decrease plant population, apply less fertilizer, adopt flexible planting dates and select shorter season varieties.

The development of RDI is not possible without first understanding patterns of tree and fruit growth. RDI must be applied during the period that shoot growth is rapid while fruit growth is slow (Fig. 2). Necessary steps for implementing RDI successfully are: Measure shoot and fruit growth to determine the RDI period for fruit species/varieties; determine the root zone distribution (width and depth); determine the wetting pattern of the irrigation system and estimate the wetted root-zone; develop a season irrigation plan (amount and interval) based on soil type and E_{pan} or ET_o, and install soil moisture sensors (depth and number depends on soil). During the RDI period: Measure and record soil suction and irrigate at -200 kPa, and irrigate to wet the top 0.3 m of the root zone. During full irrigation period: Irrigate to wet when soil suction at 0.3 m depth dries out to -30 or -50 kPa and irrigate to wet at least the top 0.6 m of the root zone. Where RDI is applied and irrigation water contains moderate to high salt content (Na or Cl) careful monitoring of soil salinity during the RDI period is necessary and strategic leaching irrigations (every 5-7 weeks) should be applied. RDI has been applied successfully for row crops like maize, soybean, sugar beet, sunflower, potato, wheat, and tree crops like citrus, olives, peaches, grapevines etc.

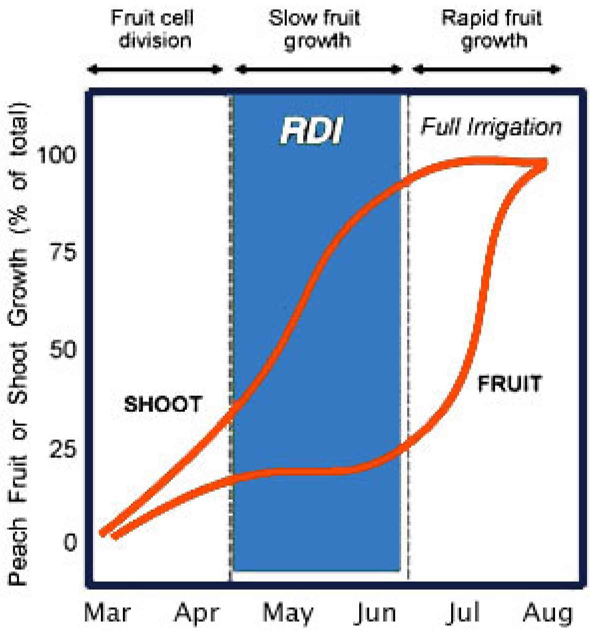

Figure 2. Typical shoot and fruit growth pattern for peach and RDI application period.

5.2 Partial Root Drying

Partial root drying (PRD) is a new irrigation technique, first applied to grapevines, that subjects one half of the root system to dry or drying conditions while the other half is irrigated. Wetted and dried sides of the root system alternate on a 7-14 day cycle. PRD uses biochemical responses of plants to water stress to achieve balance between vegetative and reproductive growth. During water stress development the vine’s first line of defense is to close its stomata to conserve moisture. One of the principal compounds that elicit this response is the abscisic acid (ABA). As soil water availability falls following the cessation of irrigation, the ABA is synthesized in the drying roots and transported to the leaves through the transpiration stream. Stomata respond by reducing aperture, thereby restricting water loss. Improvement of WUE results from partial stomatal closure. However, an inevitable consequence is reduced photosynthesis. With PRD, switching the wet and dry sectors of root zone on regular basis, this transient response was overcome.

Commercial trials with grapevines have shown that if PRD is applied properly, there should be no significant yield reduction, even irrigation amount may be halved. This contrasts with RDI technique, where savings in irrigation water application have been often at the expense of yield. Furthermore, the quality of the fruits is at least maintained if not improved. PRD has been successfully applied with drip irrigation in grapevines, with subsurface irrigation in grapevines and even furrow irrigation in pear, citrus and grapevines. The cost of PRD application varies according to the irrigation system employed and whether it is applied to new or existing vineyards. In pre-existing irrigation systems an additional line must be added. The additional cost of installing PRD, is economical where the cost of irrigation water is high and as water becomes an increasingly valuable and scarce resource. In these areas the true environmental cost of water justifies the implementation cost of PRD.

6. SUBSURFACE DRIP IRRIGATION

Subsurface drip irrigation (SDI) is a low-pressure, low volume irrigation system that uses buried tubes to apply water. The applied water moves out of the tubes by soil matrix suction. Wetting occurs around the tube and water moves out in the soil all directions. The potential advantages of SDI are: a) water conservation b) enhanced fertilizer efficiency c) uniform and highly efficient water application d) elimination of surface infiltration problems and evaporation losses e) flexibility in providing frequent and light irrigations f) Reduced problems of disease and weeds, g) lower pressure required for operation. The main disadvantages are the high cost of initial installation and the increased possibility for clogging.

Subsurface irrigation is suitable for almost all crops, especially for high value fruit and vegetables, turfs and landscapes. A large variety of tubes are available in the market from PE tubes with built-in emitters or porous tubes that ooze water out the entire length of the tube. The tube is installed below the soil surface either by digging the ditches or by special device pulled by a tractor. The depth of installation depends upon soil characteristics and crop species ranging from 15-20 cm for vegetables and 30-50 cm for tree crops.

To avoid clogging problems it is essential for SDI to use a 200 mesh filter for most tube material. Porous tubes need more frequent flushing. However, the performance and life of any system depends on how well it is designed and operated. Back flush system must be checked at regular intervals. Water quality affects the system (high pH, salinity and iron may cause precipitates). Further problems arise if water contains organic matter, bacteria or algae. For protection of the system occasional injection of acid or acid-forming chemicals or chlorine at the end of the irrigation season help to stop precipitates. After the use of chemicals, the system has to run for a while to remove residual chemicals.

7. ABSTRACT

The major agricultural use of water is for irrigation and its supply is decreasing steadily due to competition with municipal and industrial sectors. Therefore, innovations are needed to increase the efficiency of use of the water that is available. Traditional

surface irrigation methods (basin, furrow, border) require high water discharges and their application efficiencies are low (range between 50-60%), while in sprinkler irrigation (permanent or mobile) application efficiency can reach 85%. Drip irrigation is widely recognized as one of the most efficient methods for watering the crops achieving application efficiencies up to 95%. It is characterized by low rates of water application, partial soil wetting, high frequency, long duration of water application and high soil water content, while losses from evaporation, deep percolation and surface runoff are negligible. Furthermore, in water scarce regions irrigation approaches not necessarily based on full crop water requirements must be adopted to ensure the optimal use of allocated water. Deficit irrigation, an optimizing strategy under which crops are deliberately allowed to sustain some degree of water stress, is already practiced. Regulated deficit irrigation (RDI) maximize water use efficiency (WUE) for higher yield per unit of irrigation water applied by exposing the crop to certain level of water stress either during a particular period or throughout the whole growing season. In addition to RDI, partial root drying (PRD) is also a new irrigation technique that subjects one half of the root system to a dry condition while the other half is irrigated. The wetted and dried sides of the root system alternate on a 10-14 day cycle. Subsurface drip irrigation (SDI) also improves WUE of crops and reduces farming cost. The above techniques have already been successfully applied to a wide variety of crops and are suitable for low input agriculture (organic farming).

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