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Integrated aquaculture-agriculture: Fish culture and plant crops module for arid areas

Farmers guide

In partnership with

WorldFish CGIAR

Integrated aquaculture-agriculture: Fish culture and plant crops module for arid areas

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Table of contents

Introduction 1

1. Agricultural land 2

2. Optimal crop composition 3

3. Water requirements for plants 4

4. Agriculture and aquaculture in arid areas 5

5. Irrigation strategies and considerations 6

6. Designing a fish culture unit 8

7. Fish culture 11

8. Fish nutrition 12

9. Water management in fishponds 14

10. Fish health 16

11. Fish harvesting and post-harvest procedures 17

12. Marketing 19

13. Social responsibility 20

Notes 21

References 21

Appendix. Water requirements for crops in Egypt 22

Introduction

This guide explains the integration between fish culture and conventional crop agriculture and discusses how farmers can maximize benefits from using these resources.[1] The main concept for any system of integration is that the outputs of one organism or system function as a source of inputs for another organism or system. For fish farmers, this concept applies to the relationship between fish and crops, as the outputs of the fish culture can be a rich source of nutrients for crops.

An integrated aquaculture-agriculture system has the following advantages:

- Irrigating crops by water used for fish farming is a way to optimize water use.
- Aquaculture-agriculture integration is environmentally friendly, as crops benefit from the nutrients in the water used for fish farming. This minimizes the amount of additional fertilizers required and thus cost. Using nutrients discharged from fish culture units also helps reduce environmental impact.
- Producing fish in remote and rural areas, away from traditional fish farming and fishing sites, reduces transportation costs and provides fresh fish for consumers.
- A small-scale farm can use this system for either home or local consumption, or both, as it is possible to produce more than one agricultural product in relatively remote areas where fresh animal food may not be available.
- It is possible to produce organic food that has higher market value compared to traditional crops as fish culture generates organic fertilizer waste that can be used in crop fertilization.

This guide focuses on integration between fish and crops. However, farmers can introduce several other models, including livestock and poultry, in proportion to their integrated system to maximize benefits from all outputs and to increase profitability (Figure 1). When designing an integrated aquaculture-agriculture farm, it is important to consider the water requirements for growing crops, the volume of the fish culture unit and the targeted fish production.

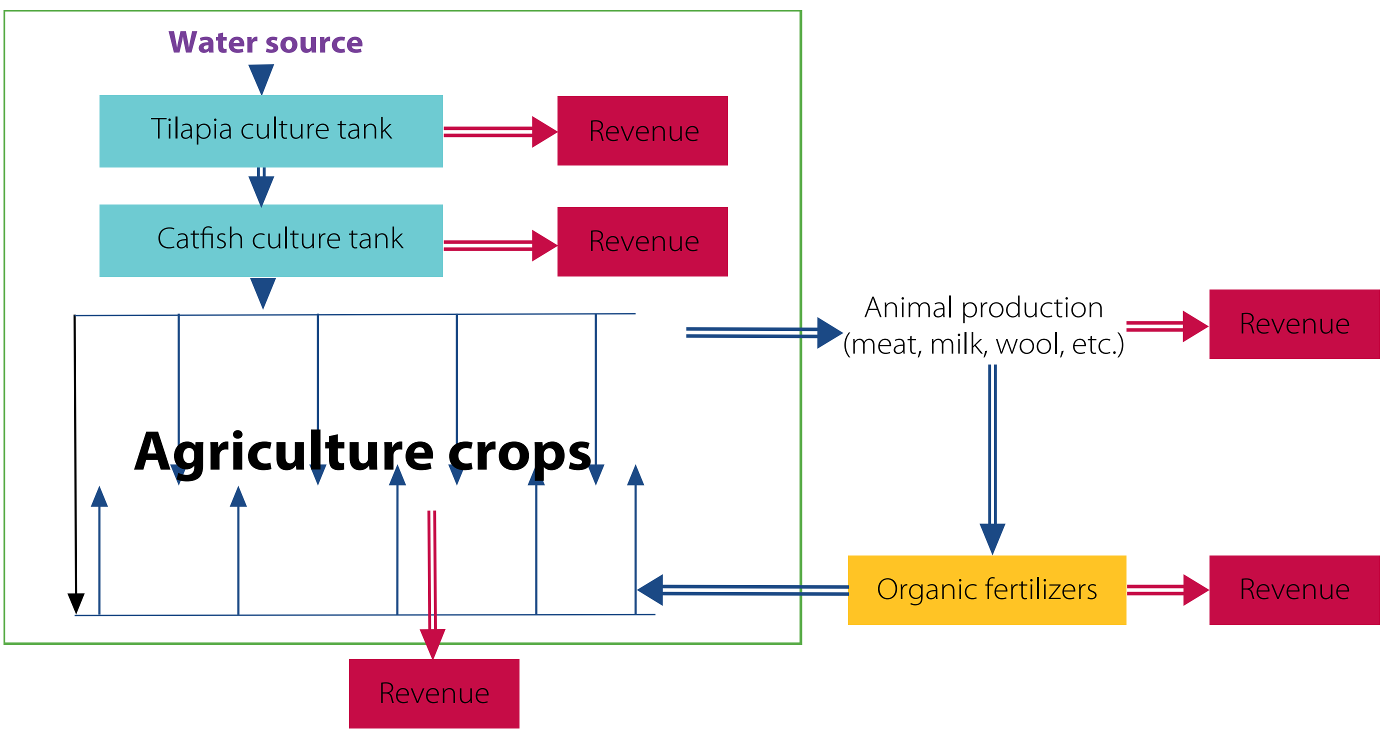


Figure 1. An integrated system comprises different types of agricultural activities.

1. Agricultural land

Agricultural activity depends on the land and water characteristics as well as the supply and demand for various crops. This affects the choice of crop composition from one farm to another.

Water requirements for land vary according to the crops grown. In an integrated aquaculture-agriculture system, farmers first need to determine how much water their crops require daily. Based on this, they can then design their fish farming system accordingly.

As to large farms, farmers can diversify their crops to maximize their use of resources. Usually, they can add an animal production component to the farm by allocating part of the land for animal husbandry and associated foraging crops, as needed. This will diversify their income sources and maximize returns on agricultural activity. For newly reclaimed sandy lands, it is best to focus on economical agricultural crops.

In areas where water availability is uncertain, farmers must build reservoirs for irrigation. This is important in places that depend on distant water sources or pumped groundwater, or when water recedes at times. A reservoir provides farmers with sustainable irrigation for their crops. It is possible to establish and exploit these reservoirs in harmony with fish farming so to maximize the benefits and other advantages, as listed in this section.

2. Optimal crop composition

In integrated aquaculture-agriculture systems, the types of crops that farmers can cultivate in addition to fish production depend on the location and the surrounding environment. For example, intercropping is a method in which fruit crops are grown with vegetables and field crops. Table 1 lists crops that are suitable for integrated farming systems in Egypt.

Field crops	Vegetables	Fruits
Wheat	Tomatoes	Mangoes
Sugar beetroots	Potatoes	Olives
Forage beetroots	Cucumbers	Oranges
Clover (alfalfa)		Tangerines
Yellow corn	Eggplants	Pomegranates
Broad beans	Peppers	Palm trees
Feed beans		

Table 1. The most suitable crops for aquaculture-agriculture integration in Egypt.

In irrigation water, the salinity concentration affects the quality of crops that can be cultivated. Some crops, such as mangoes and vegetables, are sensitive to salinity in water, while other crops, like olives and pomegranates, can tolerate high salinity levels. Table 2 shows the relationship between the total salt concentration in water and its suitability for irrigation purposes.

Total salt concentration (ppm)	Suitability for irrigation
<160	This is suitable for irrigating all crops in every type of land.
160–500	This is suitable for irrigating low saline sensitive crops.
500–1000	This is suitable for irrigating low saline sensitive crops, provided the cultivated land has a good drainage system and allows enough water to wash away any salt residue in the roots.
1000–1500	This is suitable for irrigating well-drained sandy land, if the amount of water used is increased each time and farmers choose crops that can tolerate the salinity ratio.
>1500	This water is not good for irrigation, especially drip irrigation. However, it can be used after mixing it with fresh water to reduce its salinity. The drip-spills localized irrigation systems can be used if salinity is up to 7000 ppm.

Table 2. Salt concentration in water and its suitability for irrigation.

3. Water requirements for plants

Water requirements for agricultural crops vary depending on the following factors:

- Some crops need more water than others.
- The age of the crop is important, because most crops need less water at the beginning of their growth than in later stages, so the water requirements of the crop have to be met at each stage.
- The higher the salt concentration, the more water the crop requires.
- Weather and climate conditions in each region, such as humidity and wind speed, are important.
- The type and nature of changes in soil affect crops differently.

Many other factors affect the water requirements of agricultural crops. In general, however, the average amount of water needed to irrigate an acre of agricultural land is 25–50 m^3 per day.

Farmers can refer to the characteristics of agricultural crops that show the phase of their growth, season and average amount of water needed, as shown in Tables 5–7 in the Appendix. Before referring to these tables, farmers should consider the following:

- The tables show water requirements by agricultural crops and irrigation needs, so farmers must adjust them based on the efficiency of the irrigation method they are using.
- Water requirements vary when several crops are intercropped with each other, so farmers should seek out an expert's opinion on agricultural crops.
- The irrigation method used affects the irrigation requirements of the crop. As such, it is better to use modern irrigation methods, as they are more efficient (Figure 2) and help conserve and maximize water use.

4. Agriculture and aquaculture in arid areas

Some might think that farming and aquaculture are not possible in arid areas because of a lack of water and land that can support such activities. However, some factors can make these activities possible, and even favorable:

- In many areas, there is enough well water or groundwater in the desert to have sufficient reserves to support farming and fish culture, and related activities.
- Water treatment facilities that make water reusable will prolong farming activities.
- Aquaculture is considered a method of land reclamation.
- Water discharged from fish ponds is rich in nutrients that can support the poor soil of the desert.

Of course, agriculture and aquaculture in arid areas are easy to undertake, as there are important factors to consider:

- Farmers should have soil and water analysed to determine their suitability for aquaculture and agriculture.
- They must know the changes in climate and weather.
- It is important for them to determine the best methods to save and conserve water.

Usually, government entities periodically release documents about weather and climate changes as well as soil and water properties in different regions. They even go as far as recommending areas that are best suited for reclamation and the water requirements for each crop. Farmers can follow these instructions and save the cost of paying for an analysis and avoiding the risks that come with experimental farming.

5. Irrigation strategies and considerations

There are four main methods that farmers can use for irrigating agricultural crops: surface irrigation (flood irrigation), pressurized irrigation (drip and sprinkler irrigation), subsurface irrigation and localized irrigation.

The most common of these are flood irrigation and drip and sprinkler irrigation. For integrated farming systems, it is best to avoid flood irrigation, as it is the least efficient method (Figure 2).

Sprinkler irrigation is preferred for field crops such as alfalfa, wheat and barley, while localized drip irrigation is best for spaced crops, such as trees, beetroot, corn and vegetables. These methods are much more efficient than the others.

For integrated fish farming systems, farmers should follow these instructions to avoid problems that can arise when using advanced irrigation methods:

- Use a separate sedimentation tank (Figure 3) to collect water for irrigating crops. The water is drawn from the bottom of the culture tank into the sedimentation tank, where precipitated waste is located, to avoid harming the fish.
- Place nets over the canal pipes that connect the two tanks. The size of the mesh should be large enough to allow solid waste to pass between the two tanks, but small enough that the fish cannot pass through. The water used for irrigation is drawn from the top layer of the sedimentation tank to avoid sediment at the bottom that could block the pipes.
- Use a mechanical filter to remove residual sediment in the water.

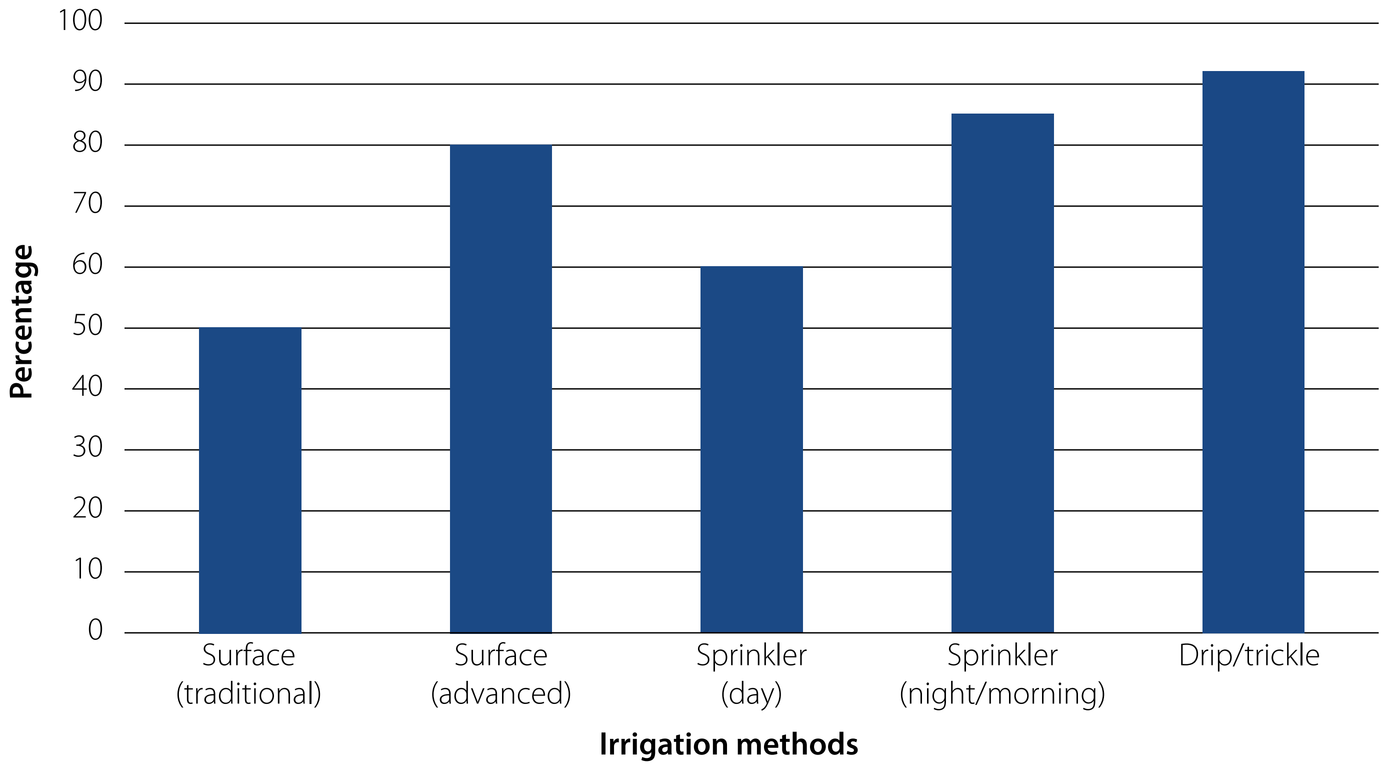


Figure 2. A comparison of the efficiency of different irrigation methods.

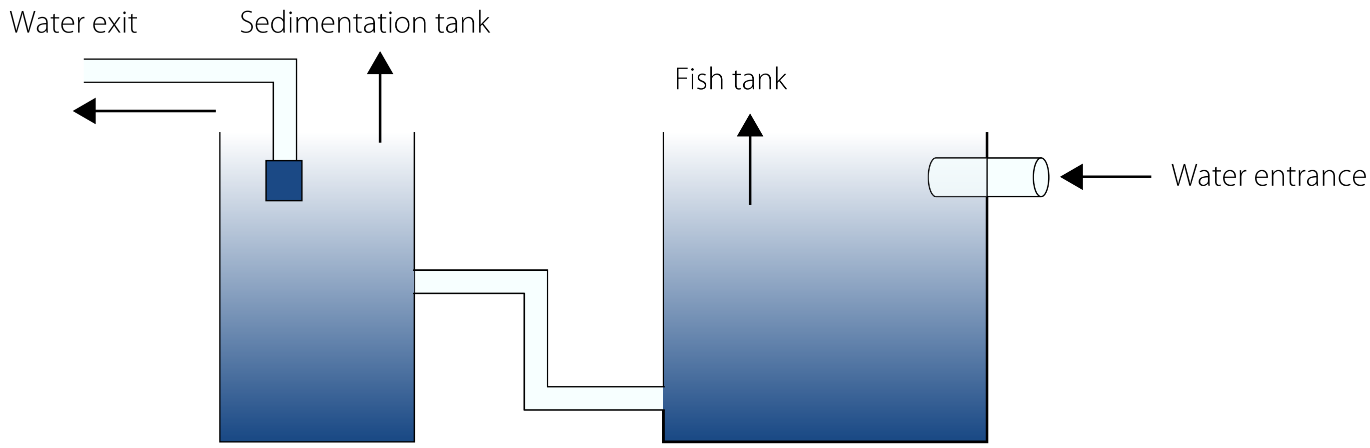


Figure 3. A fish tank and sedimentation tank, with a mesh net at the entrance of the pipe connecting the two tanks.

Farmers can use chemical compounds to dissolve suspended solids and sediment to avoid blocking pipes or sprinklers. They can also collect any sediment that has settled at the bottom of the tank and use it as fertilizer for plants. For example, phosphoric acid has a dual purpose. It is used to clean out irrigation hoses while at the same time acting as a fertilizer for plants, as it is a good source of phosphorus.

The following are concerns that farmers should take into account regarding irrigation in integrated aquaculture-agriculture systems:

- Drip and sprinkler methods require highly efficient filters to maintain the irrigation system.
- Sometimes, the water drained from the fish tanks is more than what the crops need.
- Water drained from the fish tanks contains a high percentage of dissolved nitrogen, which is an essential nutrient for fertlizing crops at the start of their growth period. However, agricultural crops need other nutrients for growth in the following stages, the most important being calcium, phosphorus and potassium. These nutrients, in their dissolved form, can be added to the irrigation water to compensate for its deficiency.
- The water used must be suitable for the type of crop and fish species being cultivated.
- The effect of enriched water on crops might not be evident in the first planting season, because the elements are stored in the soil over time. The effect of these fertilizers appears in the following seasons. This is known as the land storage effect.
- Farmers must be flexible when using water. They should stop irrigating some of their crops in winter and for pre-harvest fasting. They should also consider draining the water from their fish tanks directly into the drainage canal.
- Farmers can use water that is relatively high in salt (3000–7500 ppm) to cultivate crops that can tolerate salinity, such as olives, pomegranates and palm trees. However, they must choose a type of farmed fish that can tolerate the same salinity. As such, farmers must take into account that continuous irrigation could raise the salinity level in the soil. To overcome this problem, farmers are advised to consult an irrigation specialist.

6. Designing a fish culture unit

6.1. Size

The size of the fish culture unit and the expected production capacity must be proportional to the area of agricultural land intended for use and its water requirements. The size of the pond should be neither so big that it results in a lower rate of water exchange, nor so small that it affects the volume of water available for the fish. The more farmers can increase the exchange rate, the better it is for fish growth.

The size of the culture unit affects two important factors: the water exchange rate and the sustainable volume of water.

The rate of water exchange increases more in small units compared to large ones. The higher the rate, the better it is for fish growth. The sustainable volume of water is the amount that must be maintained at all times in order to preserve the lives of the fish. The sustainable volume will be as large as the size of the culturing unit, so farmers have to determine the size of the culture unit to maintain the balance between these two factors.

For optimal water use efficiency, the volume of the fish culture tank may vary according to an average water use for crops of m^3/day. For example, for five acres of land, with a daily water use rate of 20 m^3/acre for irrigation, a water tank of 100–200 m^3 is best, bearing in mind that the water depth suitable for tilapia culture ranges from 1 to 2 m.

6.2. Types

Fishponds are built for two reasons: for growing fish or as a water reservoir for irrigating crop-cultivated land. There are two main types of ponds: concrete and plastic-lined.

6.2.1. Concrete ponds

Concrete ponds are better for sandy soil that cannot retain water for a long time. These ponds can be square, rectangular, circular or another shape. Circular tank is the best as the shape allows for creating water current, allow easily solid removal out of tank and are in use for grow-out stage of fish farming.

Rectangular or square ponds are best for large areas of land, as they leave more space for fish farming. However, they are less efficient from the perspectives of management, drainage and waste removal. Circular or octagonal ponds are considered the best, because they are easier to manage and to remove waste. The advantage of octagonal ponds is that they aerate the water better because they have eight angles and are easier to build than circular ponds.

With rectangular and square tanks, it is better to irrigate from the top of the tank to stir the water better, while drainage should come from the opposite side of the tank to remove solid waste at the bottom. Drainage in circular tanks differs from the traditional method, as these tanks slope toward the center where the drainage hole is. The slope helps stir the water inside the tank so that it is easier to collect and get rid of waste.

Plate 1. Rectangular polyethylene-lined pond.

Plate 2. Circular concrete pond.

6.2.2. Plastic-lined ponds

A sheet of polyethylene is used to cover the entire bottom of this type of pond. Like the concrete ones, these ponds are used for sandy soil that cannot retain water. However, plastic-lined ponds are less expensive than concrete ponds. They are also suitable for relatively large areas, and they lower the amount of water that leaks into the soil.

A high-density, 1000 micron thick polyethylene tarpaulin has a shelf life of 10 years. The soil has to be free of any gravel or sharp edges that could puncture the tarpaulin and lead to water leaks. Never use sharp tools or materials that could puncture the plastic layer should never be used.

When building a fishpond, another option is to use bricks topped with a layer of cement to cover the dikes and the bottom. This technique is relatively less expensive than concrete ponds, but farmers should consult a specialist before starting construction.

Plate 3. A pond lined with plastic.

Farmers should consider the following when designing a fishpond:

- Make the best use of uneven ground surfaces, as the level of the ground will affect both irrigation and drainage (Figure 4).

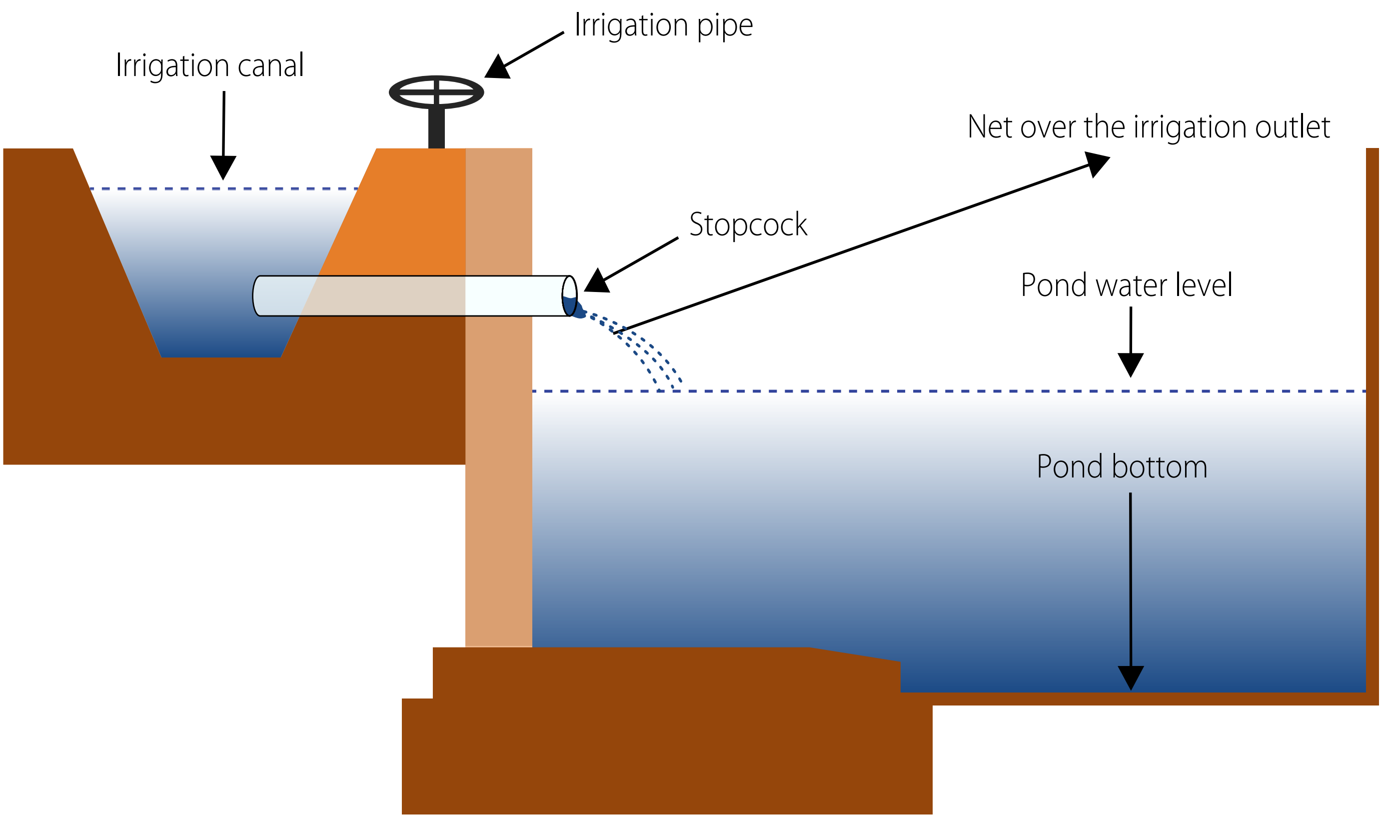


Figure 4. Recommended design for pond irrigation.

- When designing a fishpond, the drainage water must be directed straight into the drainage canal so that water can be changed regularly, regardless of whether it is needed for irrigation. When irrigation water is needed, the drainage water must be used. When irrigation water is not needed, the water could be drained directly into the drainage canal.
- When building irrigation and drainage canals, allow water to enter the pond from the top for irrigation (Figure 4) to stir the water more and to increase the level of dissolved oxygen (DO). For drainage, drain water from the bottom, where waste accumulates, must be used.
- Make sure the bottom slopes toward the drainage canal to make it easier to drain the water and collect waste. Ensure the irrigation inlet is opposite the drainage outlet.
- Build a canal around the pond and connect it to the pond to circulate the water. The movement of the water in the canal will cause waste to precipitate and increase the water quality so that it can be reused. Clear the canal of sediment regularly.

Plate 4. Using irrigation water from the top of a pond.

7. Fish culture

7.1. Cultured fish species

Many fish species are suitable for farming. In Egypt, Nile tilapia and African catfish are among the most common and widespread species. They are suitable for integrated aquaculture-agriculture systems for the following reasons:

- They can tolerate low levels of DO in water longer than other species. They can also tolerate high rates of intensification.
- They are in demand at the markets year-round.
- Seed is available for almost the whole year.
- They grow fast and can tolerate changes in environmental conditions better than other species.

7.2. Culture season

The culture season for both tilapia and catfish starts when the temperature rises, from March until November. The length of the culture season increases or decreases according to the location, climate and weather.

7.3. Fish size

It is better to culture large fingerlings to avoid high losses that occur with seed. Fingerlings also produce a higher percentage of ammonia than seeds. Ammonia is an important factor for crops, especially at the beginning of the planting season, which requires high amounts of nitrogen.

7.4. Fish source

The fish source must be reliable and trustworthy. For Nile tilapia, all male fingerlings are better, because they grow faster and do not reproduce in the pond.

7.5. Stocking rate or carrying capacity

Farms can start a culture cycle based on the average productivity in farms where the water and weather conditions are similar. For example, if the average production in a neighboring farm is 10 kg/m^3, and the average size of the resulting fish is 500 g per fish, then it is possible to calculate the stocking rate as follows:

First, calculate the biomass of the harvested fish at the end of the season:

- The number of fish per kilogram multiplied by the number of kilograms expected to be harvested per cubic meter. For example, if there are 2 fish/kg and 10 kg of fish/m^3 are expected, then the number of harvested fish would be 20/m^3 (2 X 10 = 20 fish/m^3).

Second, calculate the survival rate during the season:

- The survival rate is based on several factors, the most important of which is fish size. The larger the fish, the lower the mortality rate. For example, if the weight of the fish when cultured is more than 20 g (fingerlings), the mortality rate would be 10%, increasing gradually until it reaches 30% for lower weights (e.g. less than 1 g).
- Assuming that the mortality rate is 10%, the number of fingerlings to be cultured would be as follows: Number of harvested fish + number of expected loss (number of harvested fish x loss percentage). For example, if 20 fish are harvested, the farmer must culture 22 fingerlings per cubic meter: 20 + (20 x 0.1) = 22 fingerlings/m^3).

It is worth mentioning here that a fish tank has a maximum carrying capacity for production. This depends on several factors, such as water quality, feeding rate, availability of aeration devices, duration of its operating hours and management. For example, if customers prefer small fish, farmers who want to produce 250 g fish will have to double the number of fingerlings (22 fingerlings/m^3 → 44 fingerlings/m^3). Production will remain at 10 kg/m^3, but the size of the fish produced in the same period might have to be halved (500 g/fish → 250 g/fish).

Farmers must also take into account the relationship between field irrigation requirements and the intensity of fish farming. The higher the rate of water changes in the pond, the greater the chances of intensifying the production (an expert in fish farming ought to be consulted).

8. Fish nutrition

8.1. General criteria

- Feed is important for fish growth, especially in intensive fish farming, as it is the main source of nutrition. It is a source of ammonia, either directly, through the decomposition of feed in water, or indirectly, through waste from fish feeding and organic matter. In both cases, ammonia enriches the water and supplies it with important elements, especially nitrogen, that are needed for plants to grow. However, farmers must make sure not to use too much feed so that the level of ammonia does not get too high and that feed is not wasted. To dispose of this excess ammonia, farmers either have to replace some of the water to prevent a decline in water quality or use it for agricultural crops, which can benefit from this excess nitrogen.
- Feed is the largest part of production costs, therefore farmers should buy good quality feed produced specifically for the fish they are culturing.
- Deal directly with the factory, not a mediator, to avoid fraud or bad storage. Otherwise, only deal with a trusted mediator.
- When purchasing feed, make sure the ingredients and production date are shown on the data card and list the levels of protein, energy, calcium, phosphorus and vitamins.
- Analyze a sample of the feed, if possible, to ensure its quality, and contact the factory if necessary. How the sample is taken is important to determine the feed quality. As such, several conditions must be observed when taking a sample: (i) the sample should represent the entire feed stock, (ii) prepare the sample according to the analyses needed and (iii) preserve the sample to last long enough to complete all required analyses.
- Store various feeds separately in a suitable, well-ventilated warehouse that keeps out pests and rodents.
- Keep records of feed purchases, including the type, source, price and quantity.
- Floating feed is recommended because it minimizes feed loss and it is simple to determine when to stop feeding (i.e. when you see the fish stop eating).
- Feed small fish 1–2 mm pellets that are 30%–35% protein, and do this three to four times daily at a rate of 5%–10% of their weight. Large fish require 3 mm pellets that are 25%–30% protein, given one or two times daily at a rate of 2%–5% of their weight.
- When throwing floating feed to fish, use a "floating" ring made of hoses or pipes to trap the feed inside and stop it from drifting to the sides of the pond. This will make it easy for fish to reach the food and avoid being preyed upon by birds, as they won't have to approach shallow areas near the pond's sides.
- Follow the proper feeding method for the type and size of fish cultured. Artificial fish feed is available in different granule forms and pellet diameters (Table 3). The size of the pellets depends on the size of the mouths of the fish.
- Chose the proper granule size. As the sizes of fish often vary in a single pond, it is necessary to mix two or more pellet sizes to cover the nutritional needs of every size. To avoid that large fish eat the feed of smaller fish, place the small granules in a special feeder that only small fish can access.

Age/fish weight	Pellet diameter (mm)
Larvae to 10 days old	>0.5
10–30 days	0.5–1
1–30 g	1
20–120 g	2
100–250 g	3
250 g	4

Table 3. The relationship between the weight/age of tilapia and the diameter of feed pellets used for feeding.

- To minimize feed waste, use a demand feeder (Plate 5), which releases feed only when the fish are under it, looking for food. Fiberglass feeders are best because they last longer than those made of sheet steel, which rusts quickly because of the humidity associated with fishponds.

8.2. Feeding program

Feed fish until they appear satiated. The best way to determine this is to use floating feeds, as the farmer can see how the fish are feeding. If the fish eat all of the feed within 20–30 minutes, they do not need any more food. However, if there is still feed left over after 30 minutes, reduce the equivalent amount of feed that remains uneaten. If the fish eat all of the feed in less than 10 minutes, increase the amount of feed 10% per day until the fish appear satiated after 20–30 minutes.

8.3. Monitoring fish growth

Taking fish samples regularly is necessary to know how the fish are doing, their growth rate and the quality of the feed used and to determine how much feed is needed per day. Taking samples regularly is important to

- monitor the growth of fish in each tank;
- calculate the amount of feed needed according to weight gain;
- evaluate the quality of the feed by calculating the increased weight of the fish as a result of using a certain amount of feed (feed conversion ratio);
- estimate the expected amount of fish production;
- plan the harvest date according to the sample size and growth rate;
- taste the fish before the harvest to judge the quality before selling them;
- determine the health of the fish according to the relationship between their weight and length.

Follow these steps to obtain a fish sample from a specific pond:

- When taking the sample, avoid times of high temperatures and extreme cold, as well as fog and strong winds.
- Take the sample while feeding the fish, as this is the best time to collect the fish.
- Make sure the number of fish in the sample is sufficient and comes from different areas of the tank.
- Place the fish gently into small containers, such as buckets.
- Weigh the fish in small quantities to avoid crowding and fatigue.
- Record the data from the samples and feed quantities used for each tank.
- When taking samples to screen for diseases, do not return the fish to the pond.

Be sure not to stress the fish in order to maintain their liveliness and to avoid infections. Avoid sampling fish (i) when there are problems with the water quality in the pond, (ii) if the fish are diseased, (iii) when the pond water is too turbid, and (iv) when it is raining.

Plate 5. Feeding fish manually.

9. Water management in fishponds

9.1. General criteria

- Identify the specifications of the water used in the farm, its quantities and suitability for fish culture and production as well as crop irrigation practices.
- Analyze the source of the farm water, including salinity, DO, pH, ammonia, nitrite, nitrate, phosphorus, iron, potassium and, most importantly, pollutants.
- Monitor the pond's water quality parameters to determine the appropriate management method and whether to replace or aerate the water. This is also essential to determine the impact on crops.
- Make sure the water depth is optimal for fish growth.
- Use groundwater to keep the temperature stable and lengthen the growth period of the fish.
- As much as possible, reuse the water after it is filtered to conserve resources. This requires using mechanical and biological filters as well as aeration devices, depending on intensity levels.

9.1.1. Water requirements

There are two types of water sources: groundwater and surface water.

Surface water, such as rivers, lakes and streams, is affected by temperatures changes, depending on the weather conditions. When temperatures drop in winter, farmers have to stop feeding their fish. They also need to replace the water frequently in order to keep the temperature of the pond from dropping too low.

Examples of groundwater include well and spring water. Unlike surface water, groundwater maintains a constant temperature throughout the year, so farmers do not need to stop feeding their fish during the winter. Groundwater also reduces the fatigue of fish caused by temperature changes. If using spring water, however, farmers must make sure to measure levels of DO, salinity and iron.

As shown in Table 4, groundwater is one of the best types of water for fish farming. It contains low levels of pathogens and pollutants, so its microbial content is low. However, groundwater lacks DO, so farmers will need to use devices to increase its oxygen content.

The size of the water tank must be twice the amount of water needed for the fish. This is to maintain a sustainable volume of water for the fish.

Comparison	Groundwater	Surface water
Temperature	The temperature remains steady throughout the year.	The temperature varies according to weather conditions.
Dissolved oxygen	DO is low, so ventilation is required.	DO levels are sufficient.
Undesirable fish	It is free of unwanted fish or any other organisms.	A mesh net should be placed over the irrigation source to stop unwanted fish from entering.
Wintering	The temperature does not change, so greenhouses can be used to maintain the temperature.	The temperature needs to change, if shelter or heating is not available.
Toxic elements	Water analysis is necessary to ensure the water is suitable and free from toxic elements or metals.	Water analysis is preferred, but the risk of toxic elements or metals is low.

Table 4. Comparison between groundwater and surface water.

9.1.2. Water exchange rate

The following factors determine the rates for replacing water in a fish production unit:

- fish density (biomass)
- water requirements for crops during irrigation periods
- amount of feed added to the tank
- DO levels in the water
- availability or absence of aeration devices
- amount of organic waste and solid sediment in the tank
- water temperature
- vitality of fish and fish diseases
- algal bloom.

9.1.3. Aeration

- Aeration increases the percentage of DO in the water. It is the most important factor for maintaining the vitality of the fish and improving their appetite.
- Using aeration equipment (Plate 6) in ponds helps direct waste to the drain. If the devices are placed properly, they can help discharge the waste out of the pond.
- Consult a specialist to determine whether the pond needs aerators or paddlewheels to meet its oxygen requirements and to know when and how long to use them.
- The higher the density of fish and biomass in the pond, the more aeration is needed. Intensive culture ponds require permanent aeration.
- In high-density culture units, measure the ratio of DO daily and use the aeration system regularly whenever the ratio falls below its optimal rate. This will keep the fish from suffocating and maintain their growth rate.
- For tilapia, the percentage of DO in the water should be no less than 5 mg/L. Since the ratio of DO in the water decreases sharply during the night and reaches its lowest level before sunrise, farmers must aerate their ponds overnight.

Plate 6. Paddle wheel aerator.

10. Fish health

Preventive measures include several stages.

10.1. Pond preparation

- Get rid of floating plants and fish waste, such as dead fish.
- In case of previous diseases, disinfect the fish using quicklime, formalin or chlorine.

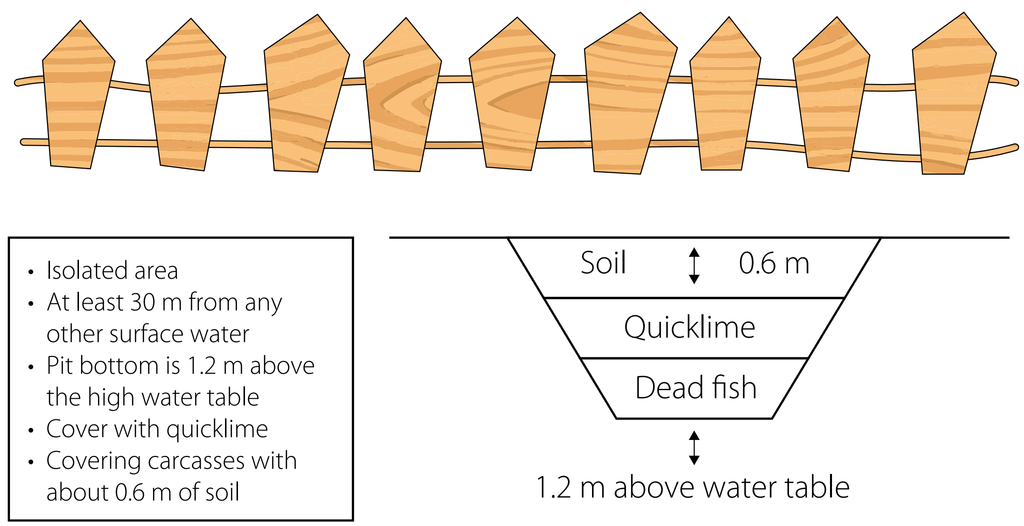
10.2. Incubating fry

- Be sure to purchase fry from a reputable source. Make sure the fry are of high vitality, uniform in size and free from apparent pathological symptoms.
- Use feed that is suitable for the age of the fry. Powdered is best.
- Follow proper preventive measures when receiving the fry, especially if they are brought from different regions. As an example, place the fry in a small separate pond and leave them for several days without feeding. If they show any pathological symptoms, they are infected. If not, transfer them to the grow-out ponds.

10.3. Fish growth stage

- Place screens over the water inlet and drainage pipes to keep undesirable fish out of the pond. This will also help control birds, which can carry diseases.
- Pay attention to water quality parameters. For example, monitor the DO and temperature daily. Other parameters, such as ammonia and nitrite, can be monitored weekly.
- Give the fish high quality feed that meets their nutritional requirements.
- Store feed properly. Avoid storing it for a long time to prevent damage and avoid the growth of fungus.
- Do periodic sampling to keep tabs on the health of the fish.
- Follow proper hygiene measures when getting rid of dead fish in the farm. Use an isolated area to dispose of dead fish safely, whether by burning or burial. If burying fish, do so at an appropriate depth and spray with quicklime afterward (Figure 5).

Generally, it is highly recommended to observe the behavior of the fish in the pond at all stages and consult with a fish disease specialist as soon as there is a change in behavior or appearance of mortality.



Source: Nasr-Allah et al. 2021.

Figure 5. How to dispose of dead fish hygienically.

11. Fish harvesting and post-harvest procedures

For integrated aquaculture-agricultural systems, partial harvesting is best because this keeps the water in the pond in order to irrigate the crops. As such, it is important to use nets when doing a partial harvest so as not to drain the water completely. If a full harvest has to be done, make sure that the canal or irrigation system can absorb the amount of water to be drained. In addition, before every harvest, farmers must be aware of the current market trends and expected selling prices to determine how many fish to harvest.

Follow these procedures when harvesting fish:

- Stop feeding the fish at least 1 day before the harvest so that they can empty their digestive tract.
- Before draining the pond, close the irrigation inlet and install nets over the drainage pipe.
- Eliminate aquatic plants and solid plankton growing on the bottom of the pond, as this can hinder the movement of the nets.
- Taste the fish before the harvest to make sure that the fish taste good and do not have unwanted odors.
- Train workers on how to catch, sort and handle fish properly.
- Drain the pond quickly, and pump the water into the drainage canal, not at the source of irrigation.
- When harvesting, avoid exposing the fish to high heat or extreme cold in the pond.
- In the summer, harvest the fish before sunrise or at sunset to avoid high temperatures when handling and transporting the fish.
- Transport the fish to the washing and sorting station as quickly as possible.
- Clean all tools and containers used to handle and sort the fish.
- Wash the fish thoroughly with clean water to maintain quality.
- Use crushed ice to keep the fish cool while washing them.
- During sorting, grade the fish in accordance with marketing sizes.

After grading, place the fish in the appropriate marketing packages according to consumer preferences. Use packages of good quality and health specifications.

When packaging fish for sale, follow these measures:

- Lay the fish lengthwise, and stack them without bending the body.
- Do not put too many fish into the box. Boxes should be no more than 30 cm high.
- Make sure the fish do not touch the sides of the box. Instead, place ice on the sides.
- Stack the fish in layers alternating with layers of crushed ice to avoid damage.

If selling live fish, weigh them and then place them in clean oxygenated water tanks fitted with an oxygen cylinder or air pump. If the fish are to be sold at an open market, use crushed ice to maintain the firmness and freshness of the fish. Have sufficient quantities of crushed ice at hand to compensate for ambient temperatures and the distance of destination.

Cover the fish boxes with clean linoleum during transportation to avoid exposure to direct sunlight and keep the ice from melting quickly. Transport the fish during the night or early in the morning, and do so in a refrigerated vehicle. It is always best to transport the fish to the market as soon as possible.

If using ice to transport the fish and maintain freshness, keep in mind that the amount of ice used must be proportional to the amount of fish being transported, as well as the ambient temperature. This should be done immediately after harvest. The faster the fish are cooled, the longer they stay fresh.

An alternative way to treat fish after harvest is to submerge them in cold water (0°C–4°C) immediately after harvesting. This will induce heat shock and keep the fish fresh before they are sold. Farmers who use this method can transport the fish to the market in a refrigerated vehicle without having to add ice.

Plate 7. Partial harvest activities in integrated tanks.

12. Marketing

- Be aware of the different markets, price changes and seasonality.
- Time harvests to take advantage of increased market demand in some seasons in order to achieve the highest return.
- For partial harvests, determine the quantity to harvest according to the needs of local markets. Focus on selling live fish to maximize returns and reduce costs.
- Harvest fish that are the size preferred by targets markets.
- To maintain quality, keep fish as fresh as possible, bearing in mind that consumers have different taste preferences.
- Take into account pre- and post-harvest procedures, and follow proper methods to ensure the fish stay firm and fresh until they reach the markets.
- Communicate with marketing associations and other producers to save time and energy and potentially reduce costs.
- Maintain good relations with producer associations, various fish market administrative groups and fish marketing groups. Fish producer associations are particularly helpful because they study the needs of the market and can help market products in different places inside and outside the country.

Plate 8. Stacking fish carefully without bending the body to avoid damage.

13. Social responsibility

Farmers should follow these recommendations to support permanent laborers on the farm and the community around it:

- Give fish to people far away from traditional fish production areas at affordable prices and in good condition.
- Allocate part of the farm's production for sale to the residents of the surrounding area at a wholesale price.
- Show the benefits of integration between the fish and crops to the local community.
- Encourage the employment of youths and women.
- Do not employ children.
- For irrigation, use water that contains high levels of fertilizer elements. This will reduce the need for agriculture fertilizer for crops and reduce the impact on the environment.
- Contribute to the social and health care of the farm workers and their families.
- Donate to charities and community development projects in the areas around the farm.
- When promoting products, be sure to mention that there are employment opportunities available on the farm.
- Employ residents from some of the areas around the farm.
- Encourage consumers to eat locally-produced fish to help reduce the consumption of imported fish of unknown origin. In addition, explain the differences between fresh and frozen fish.
- Share media promotions for fish farms that explain their safety and security to consumers and the safety of the procedures used in their production.
- Cooperate with neighboring farms to keep facilities, water canals and drainages intact and in good condition and help maintain them.
- Provide adequate facilities for the subsistence of farm workers.
- Ensure that workers are provided with the necessary supplies, such as protective gear and clothing.
- Train workers on how to use chemicals and medicines safely.
- Organize fairs and events to showcase day-to-day fish culture and crop culture system work activities, where participants could have access to the farm's records to get a sense of the day-to-day management. This could include information on daily water quality parameters, fish behavior, amount of water used for irrigation, incident reports, waste management, etc.
- Train the workers responsible for feeding fish to identify water quality warning signals and take appropriate measures.
- Train workers on biosecurity measures.

Notes

[1] For more details and information about fish farming, please refer to the 2016 issue of the Fish Farmers Guide about the best management practices for fishponds in Egypt, prepared by WorldFish.

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Appendix. Water requirements for crops in Egypt

Crop	Area	January	February	March	April	May	June	July	August	September	October	November	December	Total
Mangoes	Delta	120	170	255	277	319	383	364	329	312	276	172	130	3107
	Middle Egypt	150	212	319	347	399	479	455	412	390	345	215	163	3884
	Upper Egypt	185	263	395	430	495	594	564	511	484	427	266	202	4816
Olives	Delta	74	103	133	162	206	251	280	265	221	192	147	118	2152
	Middle Egypt	92	129	166	203	258	313	350	332	276	240	184	147	2690
	Upper Egypt	114	160	206	251	320	388	434	411	343	297	228	183	3335
Bananas	Delta	240	360	456	504	600	648	600	528	456	408	336	240	5376
	Middle Egypt	300	450	570	630	750	810	750	660	570	510	420	300	6720
	Upper Egypt	372	558	707	781	930	1004	930	818	707	632	521	372	8333
Palm trees	Delta	80	110	140	168	224	244	223	198	179	127	115	114	1923
	Middle Egypt	100	138	175	210	280	305	279	247	224	158	144	143	2404
	Upper Egypt	124	171	217	260	348	379	346	307	278	196	179	177	2981
Citrus fruit	Delta	108	153	232	272	345	402	368	359	303	272	166	120	3100
	Middle Egypt	134	191	290	340	431	503	460	449	379	339	208	150	3875
	Upper Egypt	167	237	360	422	535	624	570	556	470	421	258	185	4805
Deciduous fruit	Delta	0	0	170	255	361	428	383	468	406	276	160	0	2906
	Middle Egypt	0	0	212	319	451	535	479	585	507	345	199	0	3633
	Upper Egypt	0	0	263	395	559	664	594	726	629	427	247	0	4505

Source: Egypt's agricultural weather stations (Kafr Elsheikh-Suds-Shandweel).

Table 5. Estimated water requirements for some fruits (m^3/feddan/month).

Crop	Area	January	February	March	April	May	June	July	August	September	October	November	December	Total
Wheat	Delta	229	326	434	490	123	0	0	0	0	0	62	179	1844
	Middle Egypt	-	-	-	-	-	-	-	-	-	--	-	-	2517
	Upper Egypt	570	665	715	239	0	0	0	0	0	0	372	505	3066
Sugar beet	Delta	361	441	526	0	0	0	0	0	0	362	320	344	2353
	Middle Egypt	-	-	-	-	-	-	-	-	-	-	-	-	3291
	Upper Egypt	-	-	-	-	-	-	-	-	-	-	--	-	4452
Alfalfa/ clover	Delta	297	365	483	612	302	0	0	0	0	0	249	300	2609
	Middle Egypt	-	-	-	-	-	-	-	-	-	-	-	-	3762
	Upper Egypt	588	622	769	507	0	0	0	0	388	679	701	655	4909
Maize	Delta	0	0	0	0	132	510	821	757	238	0	0	0	2459
	Middle Egypt	-	-	-	-	-	-	-	-	-	-	-	-	3515
	Upper Egypt	0	0	0	0	344	285	1160	1139	786	0	0	0	3714
Fava beans	Delta	269	381	495	273	0	0	0	0	0	0	61	179	1658
	-	-	-	-	-	-	-	-	-	-	-	-	-	1729
	Upper Egypt	284	0	0	0	0	0	0	0	508	679	680	609	2151
String beans	Delta	91.2	261.6	566.4	480	235.2	0	0	0	0	0	0	0	1634
	Middle Egypt	-	-	-	-	-	-	-	-	-	-	-	-	-
	Upper Egypt	218	516	769	567	0	0	0	0	0	0	0	0	2070

Source: Egypt's agricultural weather stations (Kafr Elsheikh-Suds-Shandweel).

Table 6. Estimated water requirements for some field crops (m^3/feddan/month).

Crop	Area	January	February	March	April	May	June	July	August	September	October	November	December	Total
Tomatoes	Delta	91.2	228	494.4	609.6	628.8	566.4	0	0	0	0	0	0	2618
	Middle Egypt	114	285	618	762	786	708	0	0	0	0	0	0	3273
	Upper Egypt	142.5	356.25	772.5	952.5	982.5	885	0	0	0	0	0	0	4091
Potatoes	Delta	115.2	261.6	566.4	609.6	590.4	0	0	0	0	0	0	0	2143
	Middle Egypt	144	327	708	762	738	0	0	0	0	0	0	0	2679
	Upper Egypt	180	408.75	885	952.5	922.5	0	0	0	0	0	0	0	3349
Cucumbers	Delta	136.8	261.6	472.8	576	0	0	0	0	0	0	0	0	1447
	Middle Egypt	171	327	591	720	0	0	0	0	0	0	0	0	1809
	Upper Egypt	213.75	408.75	738.75	900	0	0	0	0	0	0	0	0	2261
Eggplants	Delta	-	-	-	-	-	-	-	-	-	-	-	-	3353
	Middle Egypt	-	-	-	-	-	-	-	-	-	-	-	-	4191
	Upper Egypt	288	0	0	0	0	0	0	495	721	719	594	536	3353
Peppers	Delta	91.2	352.8	705.6	710.4	787.2	739.2	705.6	0	0	0	0	0	4092
	Middle Egypt	114	441	882	888	984	924	882	0	0	0	0	0	5115
	Upper Egypt	142.5	551.25	1102.5	1110	1230	1155	1102.5	0	0	0	0	0	6394

Source: Egypt's agricultural weather stations (Kafr Elsheikh-Suds-Shandweel).

Table 7. Estimated water requirements for some vegetable crops (m^3/feddan/month).

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About WorldFish

WorldFish is a leading international research organization working to transform aquatic food systems to reduce hunger, malnutrition, and poverty. It collaborates with international, regional, and national partners to co-develop and deliver scientific innovations, evidence for policy, and knowledge to enable equitable and inclusive impact for millions who depend on fish for their livelihoods. As a member of CGIAR, WorldFish contributes to building a food- and nutrition-secure future and restoring natural resources. Headquartered in Penang, Malaysia, with country offices across Africa, Asia, and the Pacific, WorldFish strives to create resilient and inclusive food systems for shared prosperity.

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