Automatic low-cost unpowered uniform drip irrigation on sloping land

Dripper assembly with 20 drippers

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1. Introduction

This publication is designed to assist smallholders to install a state of the art irrigation system on flat or sloping land at an affordable cost. Most drip irrigation applications on sloping land use PC (pressure compensated) drippers. If a header tank is being used, a high pressure pump is usually required to ensure that all drippers within each zone are within the pressure range recommended by the manufacturer for pressure compensation. Furthermore, many zones are usually required to ensure that the drippers within each zone are within the pressure range recommended by the manufacturer for pressure compensation. All of these requirements make drip irrigation with PC drippers very expensive.

This publication demonstrates how drip irrigation on sloping land can use NPC (non pressure compensated) drippers without compromising irrigation uniformity. The irrigation controller is an Unpowered Terracotta Irrigation Controller and it is available online at the Measured Irrigation Shop: https://www.measuredirrigation.com/product-page/ .
The User Manual for the Unpowered Terracotta Irrigation Controller can be downloaded from the Measured Irrigation website: www.measuredirrigation.com.au

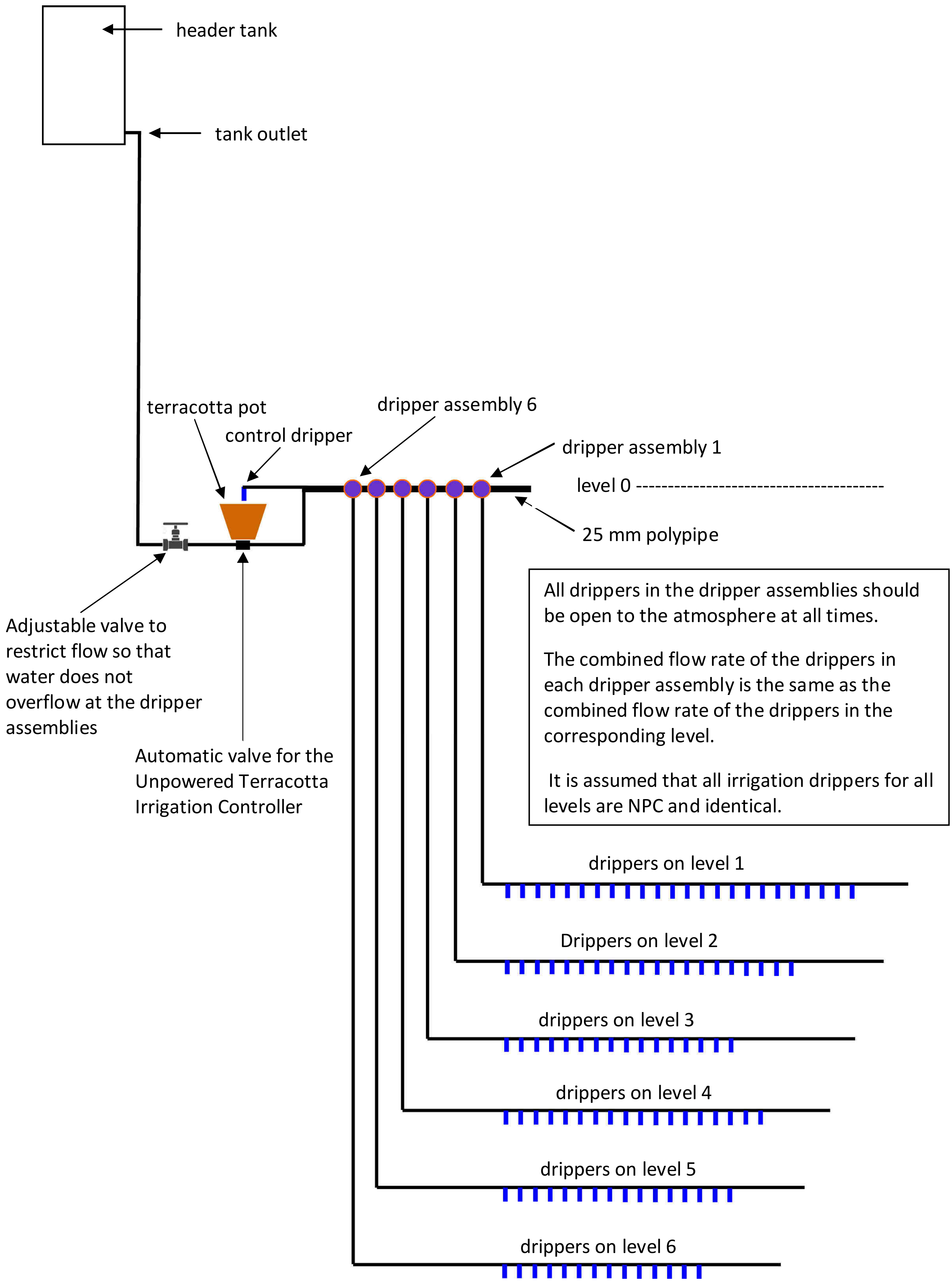
Some key features are listed below.

1. The installation cost is a fraction of the cost of an equivalent PC system.
2. Excluding the refilling of the header tank, the irrigation system is completely unpowered (no batteries, no solar panels, no electronics, no computers, and no WiFi).
3. A small low pressure water transfer pump may be required to refill the header tank between irrigation events.
4. Provided that the irrigation system is designed so that frictional head loss along each lateral is negligible, then irrigation uniformity for the entire irrigation system can be achieved.
5. Provided that all drippers (including the control dripper) have the same emitter discharge exponent (see Appendix), the water discharged from each irrigation dripper during the irrigation event is independent of pressure.
6. You can adjust the water usage rate by adjusting the control dripper on the Unpowered Terracotta Irrigation Controller.
7. You can adjust the interval between irrigation events by adjusting the float on the Unpowered Terracotta Irrigation Controller.
8. The irrigation system responds automatically to on-site evaporation and rainfall.
9. Simple, unpowered, and low tech, and therefore fewer things can go wrong.
10. No solenoid valves, no wiring, no high pressure pump, and no hose clamps.
11. Provided that you have a continuous water supply, you can leave your irrigation application unattended for weeks on end.

The irrigation method described in this publication will be referred to as the **Omodei method**. The theoretical justification for the claims made about the Omodei method will be presented elsewhere.

The Unpowered Terracotta Irrigation Controller incorporates a small valve with a half inch inlet and outlet. The size of the irrigation application is limited by the size of the valve. For large irrigation applications, the Terracotta Irrigation Controller for Latching Solenoids should be used. A small 9 volt battery provides all the power required to operate the latching solenoid.

2. Schematic diagram



3. Installation on sloping land

Step 1. For maximum irrigation uniformity, do the planting in rows so that each row (or swale) follows a contour level. The plants in each row should have the same water requirement. If plants have different water requirements, plants with a greater water requirement should be at a lower level than plants whose water requirement is less. Arrange the laterals so that each lateral is at the same level as one of the rows. The laterals may be NPC dripline or 19 mm polypipe with online NPC drippers. Restrict the length of the laterals so that frictional head loss along the laterals is negligible. To minimise frictional head loss along very long laterals you may need to deliver water from the dripper assembly to many points along the lateral (for example, at one sixth of the way, at half way, and at five sixths of the way).

Step 2. Connect the water supply to the adjustable valve connected to the inlet of an Unpowered Terracotta Irrigation Controller. If the water supply is at mains pressure, the control dripper should be as high as possible. If the water supply is a header tank, the height of the lowest operational header tank level above the control dripper should be about the same as the height of the control dripper above the highest lateral. Connect the outlet from the irrigation controller to a horizontal length of polypipe (at least 25 mm diameter) at the same level as the control dripper (this level is called level 0).

Step 3. Fully open the inlet valve. Progressively add high-flow drippers to the dripper assembly for the highest level (level 1) until water starts to overflow at the dripper assembly. The high-flow drippers should have the same emitter discharge exponent (see Appendix) as the irrigation drippers. Slowly restrict the adjustable valve until water stops overflowing. Calculate the ratio R of the number of high-flow drippers in the dripper assembly for level 1 to the number of irrigation drippers in level 1.

Step 4. Let L denote the number of levels. Let C_i $(i = 2, 3, \dots, L)$ be the ratio of the water requirement for each plant at level i to the water requirement for each plant at level 1. Let N_i be the number of irrigation drippers at level i $(i = 2, 3, \dots, L)$. Let H_i denote he number of high-flow drippers in the dripper assembly for level i. The Omodei method requires

$$H_i = C_i * R * N_i \qquad (i = 2, 3, \dots, L)$$

Attach each the dripper assembly to the horizontal polypipe in Step 2 so that all the drippers are at level 0.

Dripper assembly with 20 drippers

Dripper assembly installed showing the overflow outlet and the polypipe delivering water to the zone

Step 5. Polypipe can be used to deliver water from each dripper assembly to the laterals in the corresponding level. The drippers in the dripper assembly should be open to the atmosphere at all times (in other words, the dripper outlets should be at atmospheric pressure). If water starts overflowing at any of the dripper assemblies, you will need to use the adjustable valve to restrict the flow just enough to stop the overflow.

Step 6. Adjust the control dripper on the Unpowered Terracotta Irrigation Controller until the irrigation drippers at level 1 discharge the appropriate amount of water during the irrigation event to suit the water requirement of the plants at level 1.

The Omodei method ensures that the irrigation drippers discharge the appropriate amount of water during the irrigation event to suit the water requirements of all the plants, regardless of the level of the plants. If all plants have the same water requirement, every irrigation dripper in the irrigation system discharges approximately the same amount of water during the irrigation event

There is no upper limit on the vertical gap between the dripper assembly and the irrigation drippers (for example, the irrigation drippers may be 100 metres or more below the dripper assembly).

If you require the water discharged by each irrigation dripper during the irrigation event to be independent of pressure, replace the adjustable control dripper by a control dripper with the same emitter discharge exponent (see Appendix) as the irrigation drippers.

The discharge of the irrigation drippers during the irrigation event can be increased by connecting additional terracotta pots to the original terracotta pot so that the water level is the same in all pots. With one additional pot the discharge is doubled. With two additional pots the discharge is trebled. Continuing in this way the discharge continues to increase.

One way of connecting the pots is to drill a small hole in the bottom of the pots and to use 4 mm rubber grommets, 4 mm barbed elbows and 4 mm tubing. The drain hole in the additional pots should be plugged.

With two additional pots the discharge during the irrigation event is slightly more than trebled.

The pots are connected by 4 mm tubing so that the water level is the same in all the pots.

The Unpowered Terracotta Irrigation Controller and the Dripper Assembly are available online from the Measured Irrigation Shop: https://www.measuredirrigation.com/product-page/

For applications using dripline, the dripper assembly may be constructed using short length of high-flow dripline.

4. Example with results

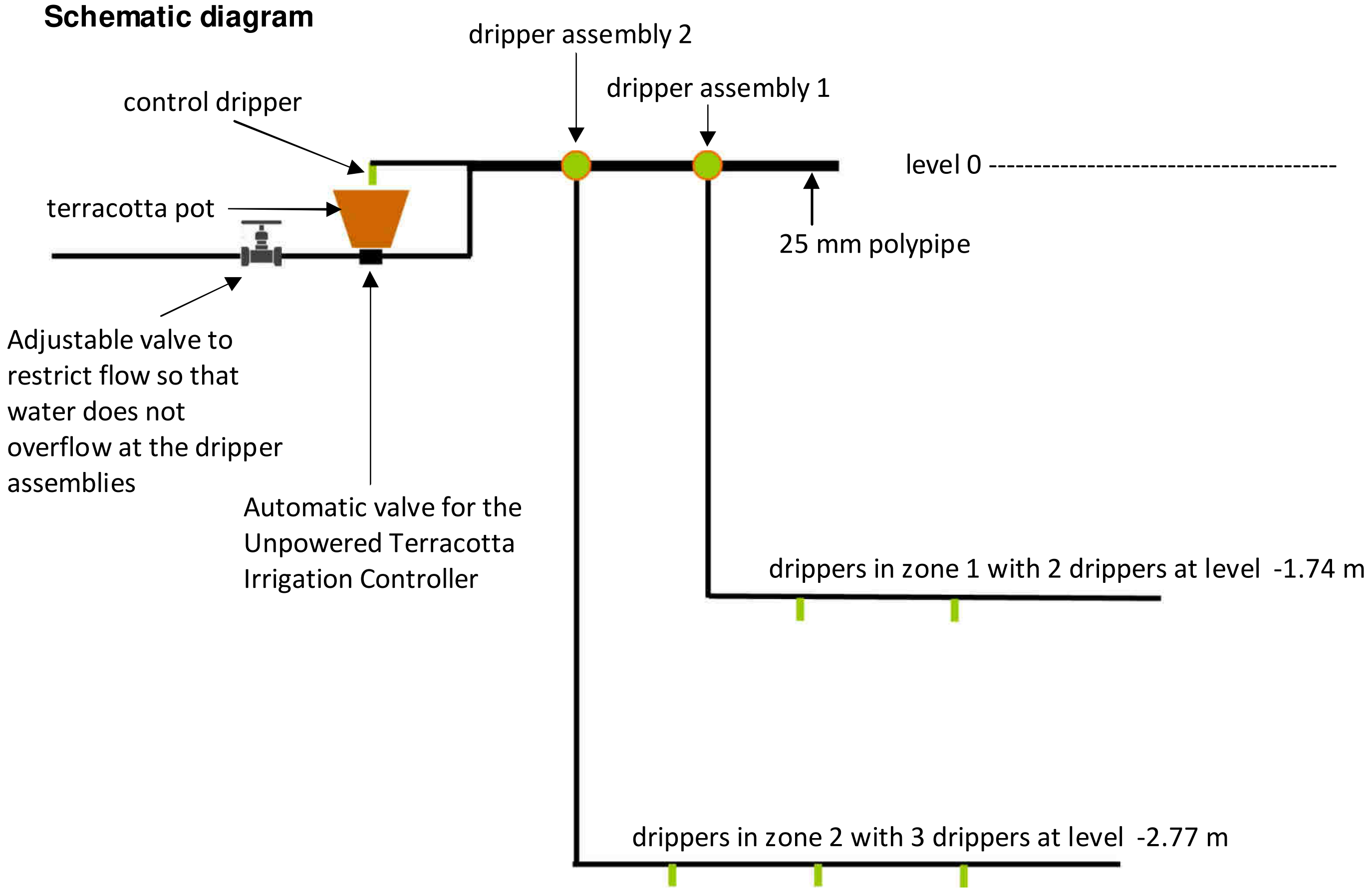
This example is used to obtain some preliminary results to test the following two claims in relation to the Omodei method.

Claim 1. Provided that the irrigation system is designed so that frictional head loss along each lateral is negligible, then irrigation uniformity for the entire irrigation system can be achieved.

Claim 2. Provided that the control dripper on the Unpowered Terracotta Irrigation Controller has the same emitter discharge exponent as the irrigation drippers, the water discharged from each irrigation dripper during the irrigation event is independent of pressure.

The drippers used for this application (including the control dripper) are all Antelco Agri Drip Classic red 8 L/H drippers (at 100 kPa). The water supply is from a mains water tap. The control dripper is at level 0, level 1 has 2 drippers at level -1.74 m, and level 2 has 3 drippers at level -2.77 m.

Schematic diagram



Results

	zone 1 dripper 1	zone 1 dripper 2	zone 2 dripper 1	zone 2 dripper 2	zone 2 dripper 3	SD	Mean	Coefficient of Variation	Uniformity
flow rate lph	2.240	2.230	2.210	2.160	2.210	0.0308	2.210	0.0139	0.986
discharge litres	0.307	0.314	0.315	0.326	0.322	0.0074	0.317	0.0233	0.977
pressure metres	0.830	0.830	0.750	0.750	0.750				
flow rate lph	1.642	1.635	1.747	1.785	1.777	0.0733	1.717	0.0427	0.957
discharge litres	0.301	0.303	0.338	0.320	0.314	0.0150	0.315	0.0475	0.953
pressure metres	0.460	0.046	0.500	0.500	0.500				
flow rate lph	1.230	1.267	1.133	1.148	1.288	0.0697	1.213	0.0575	0.943
discharge litres	0.299	0.306	0.315	0.305	0.321	0.0087	0.309	0.0282	0.972
pressure metres	0.350	0.350	0.370	0.370	0.370				
flow rate lph	0.743	0.768	0.817	0.840	0.855	0.0476	0.805	0.0592	0.941
discharge litres	0.250	0.259	0.277	0.282	0.270	0.0131	0.268	0.0489	0.951
pressure metres	0.125	0.125	0.105	0.105	0.105				
discharge SD	0.026	0.025	0.025	0.020	0.025				
discharge Mean	0.289	0.296	0.311	0.308	0.307				
discharge CV	0.091	0.084	0.081	0.064	0.081				
discharge Uniformity	0.909	0.916	0.919	0.936	0.919				
Discharge statistics when the lowest pressure is excluded									
discharge SD	0.004	0.006	0.013	0.011	0.004				
discharge Mean	0.302	0.308	0.323	0.317	0.319				
discharge CV	0.014	0.018	0.041	0.034	0.014				
discharge Uniformity	0.986	0.982	0.959	0.966	0.986				

The results support both claims.

5. Intercropping on flat land

Intercropping is the practice of growing multiple crops simultaneously.

Different crops have different water requirements and so the dripper discharge during the irrigation event needs to vary according to the crop. The crop with the lowest water requirement is allocated to group 1. The crop with the next lowest water requirement is allocated to group 2. Continue in this way until each crop has been allocated to a group. It is assumed that the same drippers are used for all crops and that the interval between irrigation events is the same for all crops.

The installation procedure for the Omodei method on flat land is similar to the installation procedure on sloping land. Instead of using a dripper assembly for each level, a dripper assembly is used for each group.

Step 1. Install the laterals for each group. The laterals may be NPC dripline or 19 mm polypipe with online NPC drippers. Restrict the length of the laterals so that frictional head loss along the laterals is negligible. To minimise frictional head loss along very long laterals you may need to deliver water from the dripper assembly to many points along the lateral.

Step 2. Connect the water supply to the adjustable valve connected to the inlet of an Unpowered Terracotta Irrigation Controller. If the water supply is at mains pressure, the control dripper should be as high as possible. If the water supply is a header tank, the height of the lowest operational header tank level above the control dripper should be about the same as the height of the control dripper above the plants. Connect the outlet from the irrigation controller to a horizontal length of polypipe (at least 25 mm diameter) at the same level as the control dripper.

Step 3. Fully open the inlet valve. Progressively add high-flow drippers to the dripper assembly for group 1 until water starts to overflow at the dripper assembly. The high-flow drippers should have the same emitter discharge exponent (see Appendix) as the irrigation drippers. Slowly restrict the adjustable valve until water stops overflowing. Calculate the ratio R of the number of high-flow drippers in the dripper assembly for group 1 to the number of irrigation drippers in group 1.

Step 4. Let L denote the number of groups. Let C_i $(i = 2, 3, \dots, L)$ be the ratio of the water requirement for each plant at group i to the water requirement for each plant at group 1. Let N_i be the number of irrigation drippers in group i $(i = 2, 3, \dots, L)$. Let H_i denote he number of high-flow drippers in the dripper assembly for group i. The Omodei method requires

$$H_i = C_i * R * N_i \qquad (i = 2, 3, \dots, L)$$

Attach each the dripper assembly to the horizontal polypipe in Step 2 so that all the drippers are at the same level.

Step 5. Polypipe can be used to deliver water from each dripper assembly to the laterals in the corresponding group. The drippers in the dripper assembly should be open to the atmosphere at all times. If water starts overflowing at any of the dripper assemblies, you will need to use the adjustable valve to restrict the flow just enough to stop the overflow.

Step 6. Adjust the control dripper on the Unpowered Terracotta Irrigation Controller until the irrigation drippers in group 1 discharge the appropriate amount of water during the irrigation event to suit the water requirement of the plants in group 1.

The Omodei method ensures that the irrigation drippers discharge the appropriate amount of water during the irrigation event to suit the water requirements of the all plants.

If you require the water discharged by each irrigation dripper during the irrigation event to be independent of pressure, replace the adjustable control dripper by a control dripper with the same emitter discharge exponent as the irrigation drippers.

The discharge of the irrigation drippers during the irrigation event can be increased by connecting additional terracotta pots to the original terracotta pot so that the water level is the same in all pots.

6. Large irrigation applications

As the size of the irrigation application increases, frictional head loss through the half inch valve at the bottom of the Unpowered Terracotta Irrigation Controller may mean that the pressure at the irrigation drippers becomes too small in some zones. With the inlet valve fully open, dripper discharge uniformity in these zones may become unacceptable.

When the size of the small valve becomes a problem, it is recommended that the Unpowered Terracotta Irrigation Controller be replaced by a suitable sized latching solenoid valve and a Terracotta Irrigation Controller for Latching Solenoids, available online at the Measured Irrigation Shop: https://www.measuredirrigation.com/product-page/.

The irrigation system is no longer unpowered. However, all of the power required is supplied by a small 9 volt battery. The User Manual for the Terracotta Irrigation Controller for Latching Solenoids can be downloaded from the Measured Irrigation website: www.measuredirrigation.com.au .

7. Installation cost

The cost of installing the drip irrigation system on sloping or flat land using the Omodei method is a fraction of the cost of installing an equivalent PC system.

- NPC drippers (or dripline) are less expensive than PC drippers (or dripline)
- If the water supply is a header tank, it is unlikely to provide enough pressure for PC drippers and so a high pressure pump is needed.
- The pressure requirement for PC drippers means that hose clamps are usually required for barbed connectors. For the Omodei method hose clamps are not needed.
- The range of pressure compensation for a PC system means that many zones are often required to keep the pressure above the lower limit for pressure compensation. Each zone will require its own solenoid valve and the cost of the solenoid valves is likely to be significant. The Omodei method is unpowered and so there are no solenoid valves.
- The PC system requires a conventional irrigation controller and electrical wiring to each of the solenoid valves. The Omodei method requires an Unpowered Terracotta Irrigation Controller and hence no wiring.
- The PC system on sloping land requires check valves to address the problem of low emitter drainage at the end of the irrigation event. Low emitter drainage on sloping land is not a problem for the Omodei method.

8. Conclusion

Measured irrigation provides a radically different approach to irrigation scheduling. Conventional irrigation systems **indirectly** control the volume of water discharged by a dripper by using PC drippers with a specified flow rate and an irrigation controller to control the duration of an irrigation event. However, measured irrigation **directly** controls the volume of water discharged by a dripper rather than controlling flow rate and time. Because it is no longer necessary to control the flow rate, one can use NPC drippers.

Measured irrigation controllers use on-site weather information rather than data from the Bureau of Meteorology, and so they are ideal for applications where on-site evaporation and rainfall are is different from BOM data from the nearest weather station (greenhouses for example).

The Unpowered Terracotta Irrigation Controller is a game-changer for automated irrigation from a header tank. Conventional automated irrigation on sloping or flat land requires the following items:

- a high pressure pump
- solenoid valves (one for each additional zone)
- conventional irrigation controller
- hose clamps
- check valves to prevent low emitter drainage (sloping land only)

None of these items are required for the Omodei method using an Unpowered Terracotta Irrigation Controller. Also, the PC drippers can be replaced with less expensive NPC drippers. Hence the cost of installing and running the irrigation system can be reduced dramatically.

The main reason for not using gravity feed irrigation on sloping land has been that the plants at the bottom of the slope get more water than those at the top. The Omodei method enables gravity feed measured irrigation to be implemented effectively on sloping land using a single Unpowered Terracotta Irrigation Controller. Even on a steep slope or a vertical garden with the same plants throughout, dripper discharge uniformity can be achieved for all irrigation drippers, regardless of level of the laterals and the vertical gap between the highest and the lowest lateral. Furthermore, low emitter drainage is not a problem with the Omodei method.

Since the development of PC drippers in Israel in 1974, the global sales of pressurised drip irrigation systems compared with gravity drip irrigation systems have grown dramatically. The market share for PC dripline versus NPC dripline continues to grow. As the cost of electricity rises, many farmers with drip irrigated areas greater than 1 ha are complaining that they can no longer afford the cost of electricity to operate the pumps needed for PC drippers. With installation and running costs growing, drip irrigation with PC drippers is becoming less viable. The installation and running costs for gravity feed drip irrigation systems is likely be much less than the costs for a PC system. Since the development of PC drippers, research and development on gravity feed drip irrigation systems has been seriously neglected. Measured irrigation provides a radically different paradigm for irrigation scheduling, and further research and development may lead to more water-efficient and energy-efficient solutions, driving a revival in sales for NPC drippers or dripline.

Appendix Emitter discharge exponent

The Netafim Product Catalogue contains the following table for their button drippers.

DRIPPERS TECHNICAL DATA

Button drippers

FLOW RATE* (L/H)	MAXIMUM WORKING PRESSURE (BAR)	WATER PASSAGES DIMENSIONS WIDTH-DEPTH-LENGTH (MM)	CONSTANT K	EXPONENT X	BASIS CODE COLOR	CAP COLOR CODE
2.00	2.0	0.98 x 0.89 x 50	0.662	0.48	Red	Black
3.00	2.0	1.05 x 0.95 x 50	0.993	0.48	Blue	Black
4.00	2.0	1.27 x 1.20 x 50	1.325	0.48	Black	Black
8.00	2.0	1.65 x 1.40 x 50	2.649	0.48	Green	Black

*Flow rate at 1.0 bar pressure

BUTTON DRIPPER
3MM BARB OUTLET

All of the button drippers have an emitter discharge exponent of 0.48.

If these drippers are used, the ratio of the flow rates of any two drippers is independent of pressure.

The Netafim Product Catalogue contains the following table for Aries HWD NPC dripline.

DRIPPERS TECHNICAL DATA

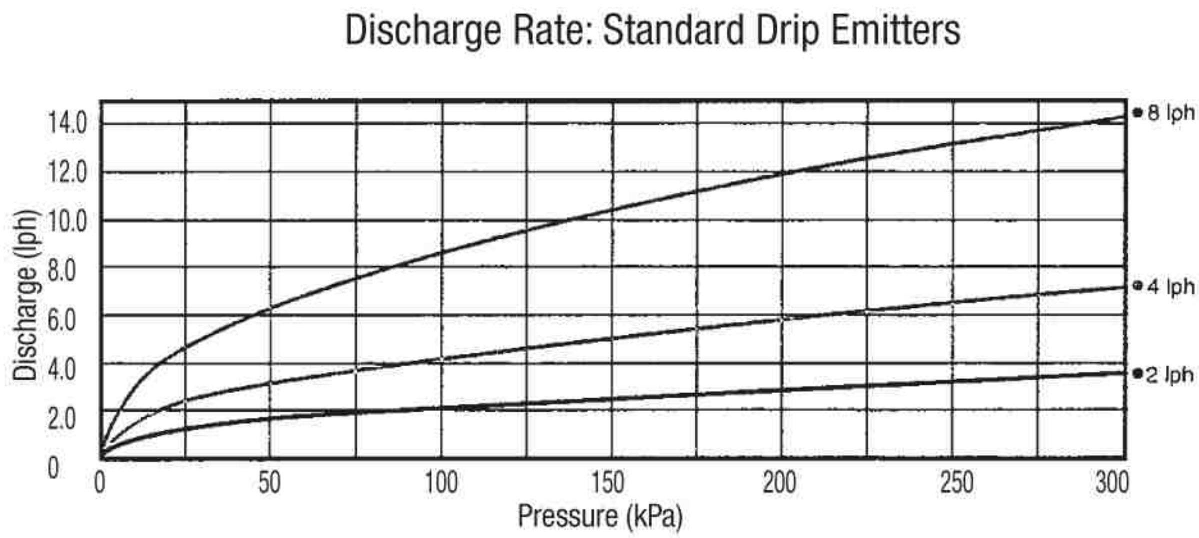
12010, 16009, 16010, 20010, 23009 - 0.9 and 1.0 mm wall thickness dripperlines

FLOW RATE* (L/H)	MAXIMUM WORKING PRESSURE (BAR)**	WATER PASSAGES DIMENSIONS WIDTH-DEPTH-LENGTH (MM)			FILTRATION AREA (MM²)	CONSTANT K	EXPONENT X	RECOMMENDED FILTRATION (MICRON)/(MESH)
0.55	3.0 up to 3.5	0.47	0.53	65	36	0.191	0.46	130/120
0.80		0.54	0.69	65	43	0.277	0.46	130/120
1.00		0.60	0.74	65	49	0.347	0.46	200/80
1.50		0.71	0.85	65	53	0.520	0.46	200/80
2.00		0.76	1.03	65	54	0.693	0.46	200/80
3.00		0.90	1.20	65	54	1.040	0.46	200/80
4.00		0.94	1.28	33	54	1.387	0.46	200/80
8.00		1.52	1.28	28	50	2.773	0.46	200/80

*Flow rate at 1.0 bar pressure **According to dripperlines wall thickness

Note that the emitter discharge exponent is 0.46 regardless of the flow rate. The dripline with a flow rate of 8 L/H (at 100 kPa) is recommended for the construction of the dripper assembly. The large range of flow rates (0.55 L/H for example) provides many options for the control dripper.

The Antelco Product Catalogue contains the following flow curve and table for their Agri Drip NPC drippers.



Performance		Standard 2 lph	4 lph	8 lph
Discharge (lph)	50 kPa	1.41	2.96	6.07
	75 kPa	1.73	3.58	7.35
	100 kPa	1.99	4.10	8.41
Discharge =	125 kPa	2.22	4.56	9.34
K x Pressure^X	150 kPa	2.42	4.96	10.18
Coefficient of Variation – CV		2.0%	2.0%	2.5%
Constant – K		0.208	0.471	0.966
Exponent – X		0.490	0.470	0.470
Minimum Cross Section (mm)		0.90x0.71	1.28x0.82	1.85x1.09

Agri Drip™ Classic
2 lph

Agri Drip™ Classic
4 lph

Agri Drip™ Classic
8 lph

Note that the red dripper has an emitter discharge exponent of 0.49 and the grey and green drippers have an emitter discharge exponent of 0.47. Therefore, if you use only grey and green drippers, the ratio of the flow rates of any two drippers is independent of pressure.