Wicking bed – a new technology for adapting to climate change

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15 Dec 2015

Update

This article was first published in 2010 and the fundamentals of the technology have proved remarkably valid over time.

However there has been major advanced in the area of soil technology for wicking beds so while readers are encourage to continue reading this classic document they are also encouraged to visit my main web site www.waterright.com.au for the latest in soil technology.

In particular we are now producing soils with over 60% void capacity which is a major advance on the 30% mentioned in the original publication allowing much greater water storage. We have also progressed in soil biology which makes nutrients much more available to the plants (and therefore us).

I welcome comments or questions to my email colinaustin@bigpond.com.

Wicking Bed Technology

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Initial publication 4 Aug 2010

As this has become an Oldie but Goldie on the Wicking Bed world I decided to make no changes to the original.

The wicking bed technology is a simple but significant technology which offers the potential to become part of a new agricultural system adapted to changing Climate. It can capture large amounts of carbon from the atmosphere providing one of the more promising ways of offsetting man made climate change. This would however require application on a significant scale.

Wicking beds are incredibly simple, yet the physical principles on which they work are involved. The first section examines this physics which may be well known to many, but how they apply to a wicking bed is less obvious.

The second section describes open and closed wicking beds, explaining why the open wicking beds system, the first to be developed is more suitable for large scale application and the closed wicking bed system, which is now widely used by environmentally sensitive growers is more applicable to smaller scale application such as horticulture.

The third section describes modified wicking beds for carbon capture.

Section 1 What is a wicking bed?

The wicking bed system is a way of growing plants in which water wicks up from an underground water reservoir. The major advantage is a significant increase in production while water use has been shown to be reduced by up to 50% of conventional practice.

Significant quantities of water are stored in the reservoir resulting in less frequent water applications, whether by rain or irrigation. Evaporation is significantly reduced. They can also incorporate water harvesting techniques which can make use of smaller rains or even dew. These are major benefits when faced with more erratic rainfall with longer periods of drought.

The wicking bed system also has the ability to improve soil quality and capture significant amounts of carbon from the atmosphere.

They are relatively inexpensive and easy to operate once the basic principles have been understood.

How wicking beds work

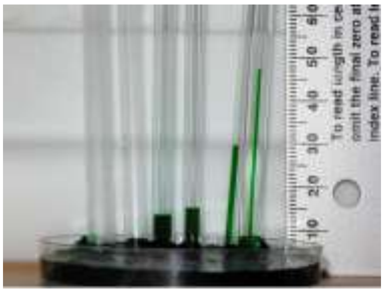
A remarkable substance

To understand how wicking beds work we have to look at the characteristics of one of the most remarkable substances on the face of the earth – water.

We are so used to water we may not realize just how remarkable water is; - its' odd behavior of expanding as it freezes, its high latent heat which aids the formation of clouds but above all its intra molecular forces. These may seem abstract physical properties but the fact is we or any other living creature would not be alive to marvel at these peculiar properties if they did not exist.

The apparently simple water molecule H_2O or perhaps H-O-H is polar - meaning that one end is positively charged while the other end is negatively charged. It is rather like a bar magnet with a North and South poles with each pole attracting the oppositely charged end of other molecules. The net result is that water has a tensile strength. We see this in the way that water forms into drops.

It is this tensile strength which pulls water up into the highest trees, as the water evaporated from the leaves it literally pulls water out of the soil through this extended chain.



While individual water molecules have the strongest attraction for other water molecules they are also attracted to many other materials such as soil particles and organic materials. These surface tension forces or wicking forces are seen when water rises in capillary tubes.

The finer the capillary the greater the surface tension forces are relative to gravity so water will rise higher in a fine tube.
If water molecules did not have this attraction there would be no plants and no food for us or other creatures, it is one of the basics for life.

Surface tension and the water holding capacity of soil.

Soil is made up from particles which generally have a wide range in size. The smaller the spaces between the particle the stronger they are held in the void.

Water is attracted to the surface of these particles by surface tension which tends to hold the water in place against gravity. The smaller particles and hence voids create greater surface tension forces, adequate to resist gravity. Water in the large holes does not have enough surface tension force to resist gravity and the water drains.

The wetting front

When water is applied to the soil surface it will initially fill the voids however water in the larger voids which cannot be held in place by surface tension will be pulled down by gravity so forming a wetting or flow front. When the water application stops the flow front will stabilize leaving the soil above the flow front being at field capacity.

The total amount of water held in place by surface tension is called the field capacity. Soils with very fine particles can hold more water than soils with coarse particles, a good loamy soil may hold about 15%.

This pattern is generally true for the theoretical homogeneous soils, in practice soils are rarely that uniform containing many cracks or fissures which allow water to penetrate deeper without wetting out the soil beside the cracks.

The drying front

Plants will extract the water from the soil starting with the water in the large pores near the surface. After a time this water will become more difficult to extract so the plant will now extract water from deeper in the soil.

This gives what is in effect a drying front. After a time the plant can no longer extract adequate water from the soil. There is still water in the soil but it is tightly locked into the smaller pores. This is called the wilt point and the amount of water between field and wilt is called the available water.

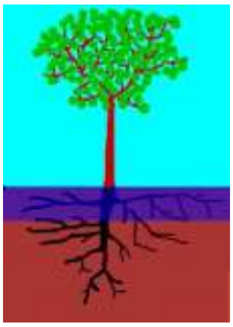
Soils with fine particles may hold more water but this water is more difficult to extract. Soils with course particles will hold less water but it is easier for the plant to extract. The field and wilt point will vary widely between different soils but the water available to the plant is generally only about 10% of the total volume of the soil.

Water holding capacity of a wicking bed

The total void content of the soil may be 30% of the total volume so if the soil is totally saturated with water then the volume of water held in the soil will be about 30% of the total volume or some double the field capacity.

The essential feature of the wicking bed system is an underground reservoir of water in immediate contact with the soil in the root zone. This water reservoir is typically filled with a coarse organic material which has a large void content and will offer less resistance to water being pulled out by surface tension from layers above. This increase the readily available water several fold, and is an important feature of the wicking bed system.

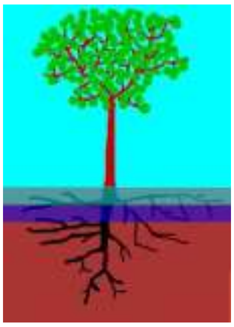
Deep and shallow irrigation



Short irrigations are very inefficient.

The water in the top surface layer (50mm) will quickly evaporate and be lost leaving the soil dry.

At the next water application this dry soil will have to be wetted before any water enters the root zone.



Typically the first 10mm of water applied will be lost. This means that short frequent irrigations are very inefficient with significant loss of water.

Deeper irrigation so the flow front just reaches the base of the roots is the most efficient. However it is very difficult to know how much water to apply so the flow front just reaches the base of the roots.

Over irrigation so the water passes beyond the root zone waste water and can also cause environmental pollution.

Water below the root zone

The soil in the root zone will become drier as the plants extract water. The small pores will create a tension trying to pull water up from below the root zone.

However this tension will be resisted by surface tension and gravity. There may be sufficient pull to raise the water a small amount possibly 20mm but in reality there is very little upward movement. Essentially any water passing beyond the root zone is effectively lost to the plant.

This water may contain nutrients which will eventually enter the water tables and possibly river systems or water supplies.

The irrigator's dilemma

If the irrigator applies frequent but shallow irrigations much of the water will be lost by evaporation. Applying deeper but less frequent irrigations is more efficient but can easily lead to loss of water past the root zone, valuable nutrients and can cause environmental pollution.

The wicking bed is a solution to this problem. In its simplest form a water reservoir catches any excess water from above ground irrigation and feeds it back to the plants as they use the water. In more advanced versions water is fed directly to this reservoir so all the plants water needs are supplied from the reservoir by wicking action.

The essential feature of the wicking bed system is the water reservoir filled with a coarse aggregate which is saturated with a significant volume of water which is not held tightly by surface tension. This water is free to wick up to the layer of soil containing the root zone.

This contrasts with the traditional system in which a much smaller volume of water is held in the soil below the root zone. The restraining surface tension forces in this soil mean there is very limited ability to wet the soil in the root zone above.

Section 2 Open and closed wicking beds

There are two types of wicking bed, open and closed. In an open wicking bed system the water reservoir is in direct contact with the parent soil. This means that water can wick upwards into the parent soil, then sideways and downwards outside the water reservoir.

A bucket filled with water with a cloth dipped into the water will empty itself completely by surface tension effects acting like a siphon. Similarly the water in the wicking bed can wick or siphon out water deep into the soil.

This makes the open system very suitable for deep rooted plants such as trees. It also has the advantage that the local micro biology and worms can readily enter the system.

In a closed wicking bed system the water in the reservoir is separated from the parent soil. This limits its use to shallower rooted plants.

Open wicking beds (left) are generally narrow and the plants grow beside the bed. Closed beds (right) are wider and the plants grow inside the bed.

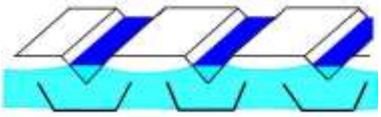
Open wicking beds

The simplest version of the wicking bed is shown. A trench is dug below the root zone and lined with an impermeable membrane (plastics sheet).

Any conventional means of irrigation can be used to apply the water, e.g. sprinkler, drip or furrow irrigation.

Any water now passing the root zone will be caught in this plastic sheet and the soil will become saturated e.g. above field capacity. This gives a significant volume of free water e.g. water which is not tightly held in place by surface tension forces and will readily wick up to wet out the root zone as it dries. Water is no longer lost but will wick upwards to feed the plant.

Filling the liner with a coarse aggregate, such as wood chips will reduce surface tension forces even further and increase the water holding capacity.



The first wicking bed used furrow irrigation giving a very simple and cheap system making it suitable for larger areas.

Open wicking beds are very suitable for large area and deep rooted plants.

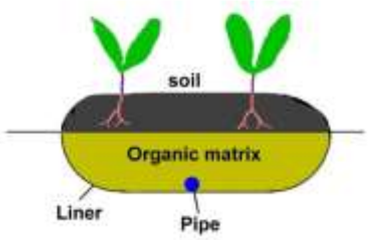
Wicking beds with subsurface feed

The next level of sophistication in the wicking beds system is to feed the water directly into the water reservoir by a pipe from the surface either directly into the water reservoir or by a distribution pipe running the length of the bed. This has an immediate advantage that no water is applied to the surface so evaporation (and weed infestation) is much reduced.

Early wicking beds used agricultural drainage pipes, modern ones use a pipe slotted only at the bottom. This prevents the pipe clogging up.

Closed wicking beds

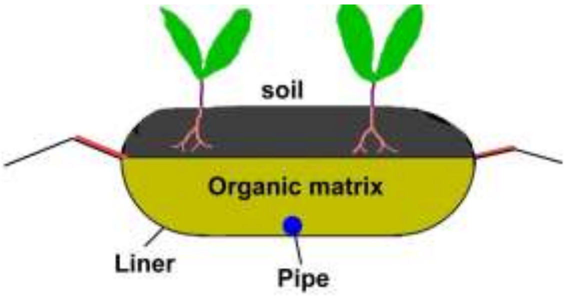
Soil in a closed wicking bed is totally isolated from the parent soil. They are more suited for shallow rooted plants such as vegetables.



The plastic sheet is now much wider extending the full width of the bed.

The simplest way of making a closed bed is to scoop out the top 200 or 300mm of soil, line the trench with plastics, place the distribution pipes, back fill with open organic mix and then replace the top soil to form a semi raised bed.

Water capture



In many areas there is insufficient irrigation water. The wicking bed system can be modified to capture and amplify rainfall by simply adding wings or extension to the wicking bed to capture water.

If for example the area of the wings it equal to the area of the bed you may think that this has effectively doubled the rainfall.

The amplification is much greater than this as small rains landing on soil only wet the surface and the water will quickly evaporate. The wings are made from an impervious material such as plastic sheet covered with stones. The water is not absorbed but instead flows down to the base of the water reservoir where it is protected. This makes use of small rains and dew otherwise wasted and is an important part of water harvesting.

Dew is a much neglected source of water as generally it is small, less than half a millimeter and quickly evaporates.

However in desert regions there is often no rain for months in the dry season so dew can significantly eke out available water. At night the stones cool down and increase the dew and the wings directing water to the base of the reservoir so evaporation is essentially eliminated.

Above ground wicking beds

Above ground beds are made in some sort of box, which makes them more suitable for smaller area.

This simple box is very cheap and is just a left over vegetable box, with a filling pipe in the centre and a drainage hole in the side.

The box is so small there is no need for a distribution pipe.

A very convenient way of making larger boxes is to drive stakes into the ground and fasten shade cloth to the stakes.

The reservoir is then formed by placing the polythene sheet in the base, laying in the pipe work, filling the reservoir with wood chips, then filling the root area with soil.

The shade cloth is very porous making for excellent drainage in a heavy rain. It is a convenient way of holding the soil in place.

Any sort of box will do as long as there is some provision for drainage. A whole variety of boxes have been used from old bath tubs to water tanks. Some people use old logs or railway sleepers to hold the soil.

Depth of wicking beds

The depth of the reservoir should not be greater than the height which water will wick upwards, generally this is 300mm. If the reservoir is deeper than the wicking height there will be a stagnant pool of water remaining which cannot feed the root zone. This will impair scheduling based on reservoir depth.

Reservoir depths of 200m work well and are commonly used. In a closed wicking bed the depth of the soil above the reservoir should be adequate to accommodate the root system of the plant. Again the normal range is 200mm to 300mm.

In an open wicking bed there must be enough soil for the water to wick upwards and sideways to the plants. A depth of 100mm will allow adequate wicking while avoiding surface evaporation.

Increased productivity

The early wicking beds were made by simply under laying a conventional furrow with a plastics liner. The initial aim was to simply stop water passing beyond the root zone and increase the water holding capacity.

An increase in productivity, far greater than expected from better irrigation, was immediately noted. The question was why? The explanation appears to lie in the differences in the way conventional and wicking beds actually work. In conventional irrigation the soil is initially very wet, above field capacity and near saturation. It is a reality that water movement through the soil is very limited until the soil is above field capacity.

This means that for a period at least, the plants roots are sitting in very wet soil which reduces growth.

In the wicking bed system the water is wicking upwards from a saturated bed below the roots and the moisture content gradually reduces to be almost dry at the surface. In other words the soil in the root zone is moist - not wet so there is adequate oxygen in the roots so the roots can breathe.

Scheduling with open and closed wicking beds

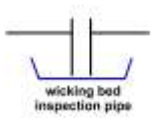
Closed beds

Closed beds are very easy to schedule.

Irrigation is needed when the water reservoir is empty. Irrigation water may be applied by any conventional means e.g. sprinkler, drip or furrow but preferably directly to the water reservoir by a distribution tube. The inspection pipe indicates when the reservoir is full so irrigation should be stopped. (A moisture sensor can be used for automatic operation).

It is not critical when to irrigate. Even if the reservoir is empty there will still be water in the soil above, so the plants will not suffer if irrigation is a little late. If there is a little water left in the reservoir it is not important as it will simply take less water to fill. However it is good to let the water completely dry up from time to time as this stops the water becoming stagnant.

Open beds



In an open bed the reservoir is filled just like the closed bed simply by looking in the inspection tube to see when the reservoir is full. It is very easy to know how much water to apply.

However after the reservoir is filled, water will wick upwards, outwards and downwards emptying the reservoir. It may take a day or two for the water to wick out completely. There is only a finite amount of water in the reservoir which means the water in the parent soil will only reach a fixed depth. This solves one of the problems of irrigation scheduling, how much water to apply. It does not answer the other question – when to irrigate.

You cannot use an empty reservoir to indicate it is time to irrigate. If you irrigated every time the reservoir was empty, say a couple of days there would be a gradual build-up of water in the soil and water lost beyond the root zone. It is therefore essential to check that the water in the soil has been used before irrigating.

The decision when to irrigate must be based on standard irrigation practices, the simplest is to have an evaporation gauge as shown and irrigate when the accumulated evaporation reaches a certain level. This level can be easily determined by gradually increasing the accumulated evaporation until the plant shows signs of stress then cutting back the accumulated evaporation to between 50 and 80% of that required to cause stress.

While the evaporation gauge is more accurate any open container, such as an old ice cream container, can give a good indication of accumulated evaporation.

Simply fill the container when you irrigate and notice how far the water level drops when the plants look as though they need water. This quickly established the bench mark so next time you can irrigate before the plant shows signs of stress.

Soil monitoring by either sensors or samplings, as conventionally used are equally effective.

Wicking bed with biological decomposition

It was mentioned that the one of the benefits of the wicking bed system is that the soil is maintained moist and is not saturated as in conventional irrigation.

These conditions are good for plants but are also good for microbial action. Soil structure is very dependent on this microbiological action, particularly the fungi which have long hyphae which exude a sticky glue like material which provide structure to the soil and keeps the soil particles apart and provide voids for roots, water and nutrients.

Some fungi, the mycorrhizal fungi, form beneficial relationship with the roots, with their fine hyphae increasing the surface are in contact with the soil by up to one thousand times.

Here different types of fungi are being tested in lab scale wicking beds.

In a wicking bed production system there is continual removal of nutrients which must be replaced. There is (or should be) very little flushing with a wicking bed so replacing the nutrients with chemical fertilizers could easily lead to over application and destruction of the sol structure.

To date the preferred method is to have a bio-box on the wicking bed where bacteria, fungi and worms can breed up and re-fertilize the soil. This can be topped up with organic waste and such fertilizers as are really needed. Inoculators of the appropriate bacteria and fungi help to decompose the waste into useful nutrients for the plant.

Water is sprayed into the bio-box which will flush the nutrients into the distribution pipe and hence to the plant roots.

Section 3 Wicking beds and carbon capture

Wicking beds have the potential to be major absorbers of atmospheric carbon.

Plants are the major absorbers of atmospheric carbon dioxide capturing some thirty times all man made emissions.

Plant materials are complex organic molecules which are readily degraded to simpler molecules, such as carbon dioxide. This happens from a number of mechanisms. The combination of U.V. light and oxygen in the atmosphere is highly destructive to these complex organic molecules. Just as anything made from polythene which has not been properly stabilized, such as a bag or disposable container, left in the sun will turn brittle and later decompose completely so will naturally occurring organic materials.

Many of the techniques to improve soil quality, such as no till farming leave organic residues on the surface which will decompose (by unzipping the carbon backbone) to simple molecules.

If the organic materials are not broken down by UV light there are likely to be decomposed by bacteria working in aerobic conditions. These aerobic bacteria will release large amount of carbon dioxide back into the atmosphere.

For these reason carbon capture in the soil is discounted in some scientific circles as a way of capturing atmospheric carbon.

Capturing atmospheric carbon

The first step in capturing atmospheric carbon is to protect the organic material from the UV in sun light. Next the decomposition needs to be largely anaerobic, with bacteria or preferably fungi. Anaerobic bacteria are more effective for soft organic material but will not attack the lignin in wood. A combination of anaerobic bacteria and fungi with worms to transport decomposed material deep into the soil, with protection from sunlight are the preferred conditions.

Dark moist conditions are required, exactly what the wicking beds provide. The appropriate micro biological activity needs to be introduced. This depends on the material to be decomposed but is likely to comprise anaerobic bacteria, species of fungi with the capacity to decompose the tougher components of wood (lignin) and deep burrowing worms.

Experiments have been conducted with specific version of the wicking bed designed for carbon capture. The illustration shows a conventional wicking bed with a biobox which is regularly filled organic waste.

Another system is to have a row of trees on one side of and open wicking bed. A row crop is grown beside the wicking bed.

There is little doubt they are highly effective in decomposition, and could decompose many tonnes per hectare.

The limit appears to be set by the availability of organic waste. This has been partially offset by having a row of trees on one side of an open wicking bed and the crop on the other. The trees can then be regular trimmed to provide a source of organic waste and nutrients.

However as carbon dioxide emissions are measured in billions of tonnes alternative sources of organic waste need investigating.

Commercial forestry is a potential source of bulk organic material which already produces large volumes of waste which are currently burned. (This in itself is an indication of how little progress we have made in reducing carbon emissions.)

Urban waste is another potential source of bulk organic waste, in which significant progress has already been made in Australia but still using largely aerobic decomposition. However anaerobic inoculants are already available and are being more widely adopted.

Financial incentives

Modifying agricultural practices to absorb atmospheric carbon adds expense to farming. The reality is that growers operating in a competitive environment, particularly when food distribution is an oligopoly so producers are price takers.

The Copenhagen conference was a tragedy. We have the technology to absorb significant quantities of atmospheric carbon in the soil but now there is no longer the international pressure and legislation to provide the incentive for individual Government action.

Let us hope that this does not stop individual Governments from introducing such schemes as part of their global responsibility.