SOIL FACTORS AFFECTING WATER USE EFFICIENCY IN SUGARCANE

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Abstract

Water use by crops has long been recognised as a function of meteorlogical, plant and soil factors. In the South African Sugar Industry cane production in the dryland areas is often severely limited because of inadequate and often erratic rainfall. As evapo-transpiration exceeds precipitation in at least 7 months of the year, the soil medium will largely determine water use efficiency by the sugarcane crop and the degree of moisture stress that may follow.

The dynamics of soil water, intake rate and run off, redistribution of water in the soil profile, drainage and evaporation ultimately determine how much moisture is available and at what rate the moisture is released. Water use efficiency (WUE) in sugar belt soils can range from good (>9tc/ha/100mm rainfall) for cane grown in Hutton soils, to poor (<5tc/ha/100mm) in the grey soils of the Glenrosa and Longlands forms. In this paper a range of soil factors and mechanisms that can potentially affect root development and therefore WUE by sugarcane are considered. These include soil aeration, soil temperature, soil depth, bulk density, texture, structure, porosity, crusting, organic matter, salinity and nutritional factors such as P deficiency and Al toxicity.

Practices that conserve soil moisture by returning organic matter such as green cane harvesting with retention of a trash blanket, incorporation of organic residues through vertical mulching, planting of green manure crops, ridge tillage planting which promotes root development, controlled infield traffic with minimum tillage, all merit consideration in improving root development and water use efficiency by sugar cane.

Introduction

Water requirement depends on both growth and transpiration and is related to environmental factors such as climate, soil fertility (mineral nutrition) and soil moisture stress. The effect of soil fertility and soil moisture stress on the water requirement is less marked than climate and published experimental evidence is also lacking.

Water use efficiency (WUE) is determined by how well these factors are manipulated in order to maximize yield from every unit of available moisture. This paper will address those soil properties and practices that management could use to improve WUE.

As WUE can be defined in many different ways, the emphasis in this paper will be on factors affecting soil water availability and the potential effects on root behaviour.

The following soil factors that affects water use efficiency are discussed and appropriate action suggested to manage each for optimal WUE: surface crusting, salinity, acidification, root distribution, soil depth, bulk density, texture and structure.

Chemical properties

Salinity

In arid regions where evapotranspiration exceeds rainfall, salt accumulation often increases until osmotic pressure of the soil solution becomes a limiting factor. However it has been shown that as the osmotic pressure of the soil increases, the osmotic pressure of the plant also increases up to between 500 and 600 kPa (Bernstein, 1961). To achieve this, plant growth is reduced by the accumulation of salt required to build up the osmotic pressure of the plant to maintain turgor. More research is required to explain the effects of high salt concentrations in the soil solution on water absorption and plant growth.

Action should be aimed to prevent the development of saline conditions. These include irrigation with good quality water, provision for subsurface drainage and regular soil analysis for signs of salinity. For existing saline conditions ensure that drainage capacity is sufficient, apply irrigation techniques to remove excess salts such as the border bed method or deep leaching with good quality water. The soil should also be analysed where possible to a depth of 90cm and follow the recommendations after consultation with your extension officer.

Soil aeration

Inadequate aeration from perched or high water tables interferes with root growth and water absorption of most crop plants except rice. One effect is decreased root permeability, which interferes with passive absorption of water. Another is reduced salt accumulation in roots, which in turn reduces or stops active absorption. The chronic aeration deficiencies found in many fine-textured soils are probably more important factors in reducing crop yields than the less common but more severe effects from saturation.

Aeration problems could be caused by surface crusts, compaction layers at the surface or at depth (the latter could result in frequent temporary water tables) and too frequent irrigation of soils with a high clay content. If the latter is unavoidable ridges should be constructed to speed up the drying rate of the soil and thus to improve aeration of the area in the immediate vicinity of the stool.

Aeration could be improved through the installation of subsurface drains in the case of wet soils and by mechanical loosening of the soil where the problem is due to surface crusts or compaction at depth.

Organic matter

Organic matter facilitates to improve water and nutrient retention properties especially of poor sandy soils by increasing the surface area available for absorption. Turpault *et al.* (1996) determined that the cation exchange capacity of 6% soil organic matter is roughly equivalent to that of mineral soils containing 45% clay of the montmorillonitic type. This information helps to explain why a relative small quantity (large in volume) of organic matter is capable of significantly improving the chemical, biological and physical properties of sandy soils. Organic matter which is used as a mulch on the surface also facilitates the reduction of water loss through weeds and evaporation and thus improves water use efficiency. Thompson (1990) obtained a mean yield increase of at least 7 tons cane/ha due to trashing(from 47 crops).

Nutrition

Although not a problem in the lowveld areas, acid soils occur under dryland conditions, where aluminium could reach toxic levels which results in stunted roots. Up take potential of water by the plant is thus reduced and WUE affected where the applied water is correlated with yield. WUE is also affected by the over or under supply of nearly all nutrients which will cause plants to experience nutrient stress resulting in smaller plants and reduced yield.

Soil and leaf samples should be submitted regularly for analysis and appropriate action taken after consulting the local extension officer.

Physical properties

Soil temperature

Water absorption is significantly reduced at soil temperatures below approximately 20°C. This reduction is much greater in warm season crops than in cool season crops. The principal cause of reduced water absorption is the reduction in root cell permeability and increase in viscosity of the water, which increases the resistance to passive movement of water through roots. A decrease in the rate of water movement in the soil is also of importance especially fine textured soils. A low soil temperature also leads to reduced metabolic activity of roots and reduced root growth, which may significantly reduce the water-absorbing surface.

Low soil temperatures is a problem mainly in the higher altitude areas where ridges could be used on deep dryland soils with a high total plant available water capacity to increase the heat absorbing area of the soil and thus the soil temperature in the immediate vicinity of the stool and near surface roots. In Vertisols, soil temperatures below 18^0 C have also favoured fixation of applied K, which will result in reduced uptake of K by the plant and a potential reduction in water use.

Texture

Soil texture (clay content) determines the geometry of the pores of that soil. In general most plant available water is held in the finer pores. Thus irrigation frequency of sandy soils prone to water losses due to leaching should be at short intervals with small applications, which reduces the efficiency of the available water. On the other hand, smaller pores also means slower water conductance through the capillaries and in soils with clay contents of 45% and higher slow water conductance will cause plants to wilt on hot and windy days even though the soil is wet.

Soil water and nutrient retention properties of sandy soils can be improved through the regular addition of organic matter or mixed with a soil containing a higher clay content. The latter option might be too expensive to be practical.

Structure

In general soils must contain relatively high clay content for structure units to be present. Soils containing small (<10 mm diameter) structure units, especially where these units extend to the soil surface, fall into the category of probably the most efficient in terms of water infiltration, storage capacity and water release properties. Soils containing large structural units (>50 mm diameter) have a significant negative effect on water use efficiency because water absorption rates are slow, enhancing the possibility of runoff and erosion. The water retention characteristics of structured soils are also generally good but the rate of water release is slow especially if water has to move from the centre of structure units to the surface where the majority of roots are found. This could lead to wilting on a warm and windy day although the soil contains sufficient amounts of water. Where the structured horizon is abruptly overlain by a sandy layer, water use may be significantly reduced due to a restricting rooting depth and reduced water infiltration rate, once the wetting front has reached the structured horizon.

Where the structured layer is within 250 mm from the surface, its negative effects could be eased through deep ripping or vertical mulching (SASEX information sheet no 4.9) .In practice an ameliorant is incorporated to depth to ensure that the disturbed effect will last for a number of years.

Crusting

Crusts form mainly on the surface of soils with a sandy loam to sandy clay loam texture through the cumulative impact of water droplets from overhead irrigation or rain falling on a bare soil surface. A crust with a thickness of only about 1 mm is enough to reduce gas exchange rates and water infiltration rates leading to runoff and erosion and reduced water use efficiency.

Protection of the soil surface by a trash layer is very effective to prevent crust from been formed. Scarifying the surface can alleviate existing crusts.

Tillage

Evaporation of water from the soil is through the upward conductance along the pores. It is only at the surface that water is converted into the gas phase, which evaporates into the atmosphere. Water movement in the gas phase is slower than in the liquid phase. To reduce water loss through evaporation dryland farmers growing annual crops lightly cultivate the soil to a depth not deeper than about 70 mm to disrupt the continuity of pores and hence to reduce water loss.

Bulk density

The maximum amount of water retained by the soil at saturation is decreased by compaction (Warkentin, 1971). But water retention at suction values greater then 10 kPa (field water capacity towards permanent wilting point at 1500 kPa) is of most interest for studies on availability of water to crops. The relationship between water availability and soil density is heavily influenced by soil texture and the amount of organic matter present. Over a range of organic carbon contents the general pattern is one of decreasing available water with increasing bulk density.

Comparing the data from Archer and Smith (1972) in Table 1 it is clear that for sandy soils with a low plant available water capacity that an increase in bulk density can be beneficial. However, on heavier soils the optimum[1] bulk density seems to be lower than the bulk density of fields under cultivation and hence the problem is to keep the bulk density as low as possible. Thus an increase in bulk density in fine grained soils will lead to an decrease in the amount of macro pores thereby reducing plant available water at low suctions. At high suctions an increase in bulk density increases soil water retention (not plant available) and the net effect is thus a reduction in plant available water.

In terms of water use efficiency this should be improved in sandy to sandy loam soils with an increase in bulk density due to improved water storage capacity and higher plant available water capacity. In soils with a high clay content the effect on water use efficiency will be the opposite due to reduced water storage capacity and plant available water capacity.

Although an increase in bulk density might improve water retention properties of certain soils, high densities are undesirable in all soils as root penetration resistance is increased which tends to limit growth and distribution and thus reducing WUE.

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[1] Optimum density is the bulk density where plant available water is at a maximum.

Table 1: Optimum bulk density for maximum plant available water and field range bulk densities for a range of textures (after Archer and Smith, 1972).

Soil	Optimum density g/cm^3	Field density (under cultivation) Range g/cm^3	Mean g/cm^3
Loamy sand	1.75	1.23 – 1.59	1.52
Sandy loam	1.50	1.05 – 1.72	1.34
Silt loam	1.40	No data	No data
Clay loam	1.20	0.94 – 1.57	1.30

High water table

Excess water means that nearly all pores are filled with water below the water table level. Thus oxygen diffusion at deeper depths for all practical purposes is halted and carbon dioxide levels rise due to organic matter decomposition and microbial activity leading to the development of hormonal imbalances. Roots are damaged leading to reduced water uptake and nutrient stress. The seriousness of this process depends on depth of the water table from the soil surface. Rudd and Chardon (1977) reported a yield decline of 0.46 ton cane/ha for each day that the water table is within 0.5 m from the surface. On the other hand a water table at a depth of 1.6 m account for between 25 to 50 % of the water use by sugarcane (Chang and Wang, 1983) thus increasing WUE substantially.

A number of options are available to solve this problem where the water table is a yield-limiting factor. These include growing cane on ridges (SASEX information no 3.1), installing mole drains (SASEX information sheet no 3.2), the construction of cambered beds (SASEX information sheet no 3.3) and installation of subsurface drains. However, it is possible that where the water table is near the surface for a large part of the year that the site is a possible wetland in which case it is recommended to revert it back to its original state.

Soil depth

Soil depth is an important parameter in the quantification of total plant available water. Even soils with a high clay content but a shallow depth will have a small capacity to store water. Irrigators will therefore have to irrigate more often to avoid water stress and yield loss. It is a well-known fact that water use efficiency decrease with an increase of the number of irrigations per time unit. On shallow soils it is thus important to select the most efficient irrigation system as a means of applying water.

Effective rooting depth (ERD) used to convert available water content (AWC, mm/m) to total plant available water (TAW, mm) is an dynamic value which changes with cane age especially in the immediate period following planting or harvesting. TAW is thus a function of the depth in which the majority of roots found and the value is different for young germinating cane compare to grown cane. ERD increase by about 11 mm/day (Wood and Wood, 1967) in most soils in summer and could come to a complete halt in winter if cold enough. To be practical TAW should be calculated for the first 50 days after plant or harvest and the potential TAW for the period thereafter.

Where soil depth is limited due to the abrupt change in clay content, the presence of a plinthic layer, compaction or weathered rock vertical mulching should be considered to break through the limiting layer and to incorporate an ameliorant to keep this passage open.

Conclusion

WUE is affected by a number of soil factors and agronomists should be aware of these factors and the agronomic practices that are available for managing these limitations. Special care should be taken with those properties that cannot be seen such as depth limiting layers and drainage beyond rooting depth. A good practical tool for growers is to dig a pit across the row to determine root behaviour to depth. The latter is especially of relevance in young cane where the TAW is far smaller than that for grown cane and which is thus an important factor reducing WUE. Another source of reduced WUE is that in-sufficient space is left for rain when irrigated. Ideally after irrigation the soil should be able to receive a further 10 to 20mm (depending on the area and season) before field capacity is reached. Still another factor affecting WUE is frequency of irrigation. Water loss through other routes than transpiration is greatest during and just after irrigation. Thus, maximum use should be made of the water holding capacity of soils in order to keep irrigation intervals as far apart as possible.

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