Suitability indicators to assess specific site, risk-based irrigation water quality

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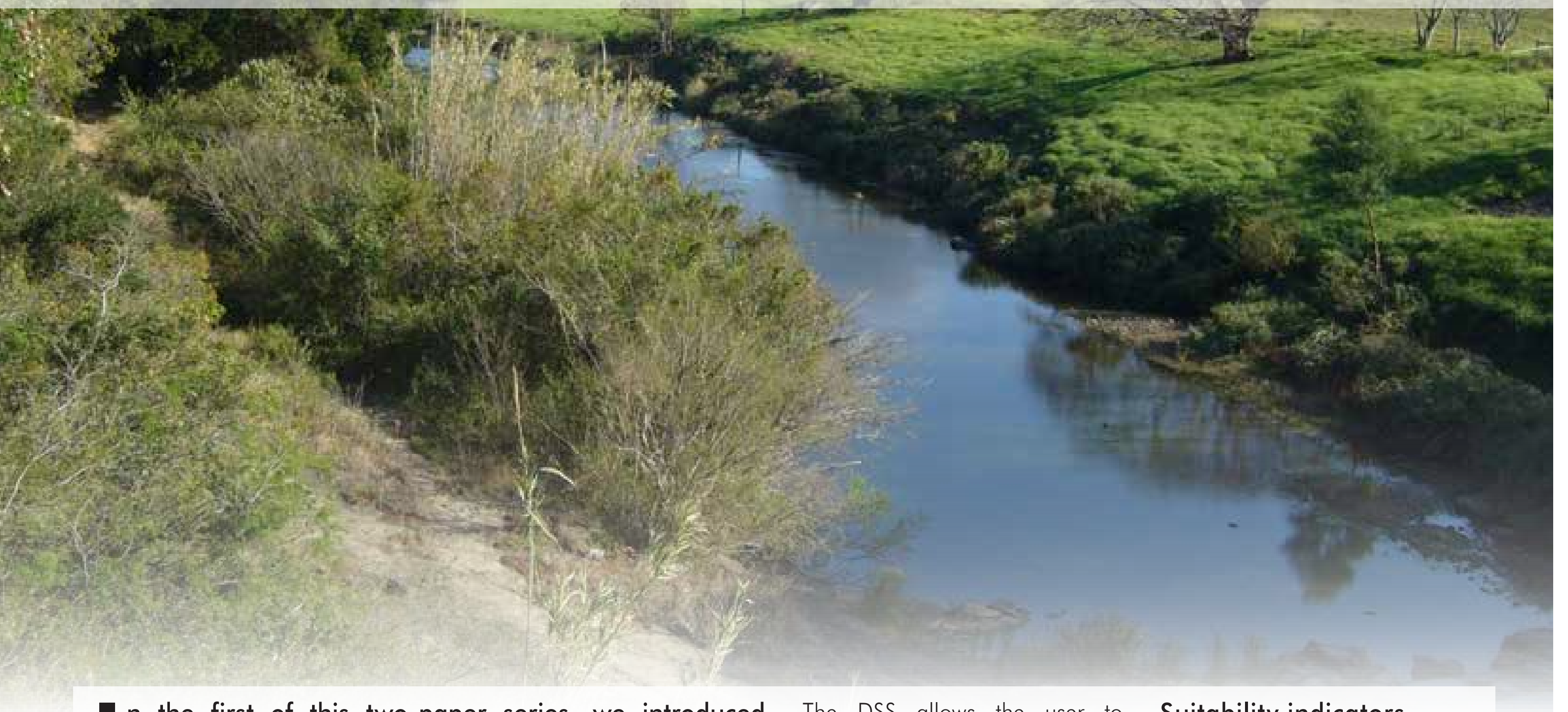

In the first of this two-paper series, we introduced readers to a newly developed electronic Decision Support System (DSS) that helps the user to assess the fitness for use of irrigation water (du Plessis et. al., 2019). In this paper, we provide an overview of the suitability indicators used by the DSS to assess the fitness for use of water for irrigation.

The DSS provides the user with an assessment of how water of a given composition will affect soil quality, crop yield and quality, as well as irrigation equipment. Specific indicators were identified with which to measure the suitability of irrigation water for its intended purpose and criteria have been established with which to categorise the effect on each suitability indicator. The criteria are used to quantify the effect that water constituents have on suitability indicators and categorise the effect as being either ideal, acceptable, tolerable or unacceptable. Throughout the DSS use is made of these (colour coded) fitness for use categories to classify and display the suitability of irrigation water (see Table1).

Table 1 A generic description of the fitness for use classification of irrigation water used by the DSS

Fitness for use category	Description
Ideal	A water quality that would not normally impair the fitness of the water for its intended use
Acceptable	A water quality that would exhibit some impairment to the fitness of the water for its intended use
Tolerable	A water quality that would exhibit increasingly unacceptable impairment to the fitness of the water for its intended use
Unacceptable	A water quality that would exhibit unacceptable impairment to the fitness of the water for its intended use

The DSS allows the user to conduct either a rapid conservative (Tier 1) or an extensive site-specific (Tier 2) evaluation of the suitability of a specific water for irrigation. Should the Tier 1 FFU assessment (that makes use of conservative assumptions) not indicate potential problems with any of the suitability indicators, the water is deemed fit for use on all crops, under all but the most exceptional circumstances. On the other hand, should the Tier 1 assessment identify potential problems with one or more of the suitability indicators, a more detailed, site specific assessment as provided by a Tier 2 assessment, is indicated. The Tier 2 assessment allows the user to select more appropriate site specific variables (such as crop, irrigation system and management, soil texture and climatic data) to simulate soil-plant-atmosphere interactions with a soil water and solute balance model, and produce a much more rigorous assessment of soil-crop-water interactions. Running the Soil Water Balance (SWB) model over several years, allows the calculation of the likelihood of yield and other parameters falling in different suitability categories.

Suitability indicators of soil quality

Four suitability indicators are used to evaluate the effect water constituents have on soil quality, namely root zone salinity, soil permeability, dissolved organic carbon loading and trace element accumulation.

Salinity (salt content) within the root zone reduces crop growth by reducing the ability of plant roots to absorb water from soil. While the yield of some crops is already affected at low soil salinity levels, others display salt tolerance, with the result that the range of crops that can be successfully cultivated decreases as soil salinity increases. Root zone salinity is thus an important indicator of soil quality, and the crops that can be cultivated successfully under irrigation.

The suitability of a soil for cropping is to a large degree determined by its ability to conduct water and air (permeability) and on physical properties that control the friability of the seedbed (tilth). In general, increases in soil sodium concentrations cause a deterioration of soil physical properties. The undesirable effects associated with sodium affected soils, are counteracted by soil salinity. For purposes of the DSS, soil infiltrability, operating at the soil surface, and hydraulic conductivity, operating within the bulk of the soil, were selected as indicators of the effect sodium and salt content of irrigation water, has on **soil permeability and other physical properties.**

Even low sodium concentrations at the soil surface can lead to crust formation and reduced infiltrability under rainfall or low salinity irrigation applications. The implication is that the infiltrability of irrigated soils can be negatively impacted by rainfall or overhead irrigation with low salinity water during the period of incomplete vegetative cover when rain or overhead irrigation droplets hit soil surface particles and form surface crusts. In line with the philosophy of using conservative assumptions for Tier 1 evaluations, it is assumed that low salinity rainfall will determine the effect of soil surface sodicity on soil infiltrability. For Tier 2 evaluations, the EC of the actual water application (rain or irrigation water) and the degree of crop cover (which protects the soil surface from crust forming droplets) are used to calculate a worst seasonal value.

Soluble salts move, redistribute and accumulate in soils largely as a result of water movement. The distribution of sodium and salts within a soil profile is thus largely determined by soil and water management practices which affect water distribution within a soil. The concentration of sodium and salt within the different soil layers are calculated to derive a qualitative measure of the degree to which the hydraulic conductivity of sensitive soils would be affected by the combined effects of soil water salinity and soil sodicity.

While a high soil organic matter content in soil, and by implication organic carbon in irrigation water, is considered as advantageous, excessive concentrations of organic carbon in irrigation water can give rise to the development of anoxic conditions, plant root stress and unpleasant odours. It is therefore important to ensure that short term overload does not occur. The criteria used to indicate the likelihood of undesirable consequences linked to the **Chemical Oxygen Demand (COD)** of irrigation water, are thus based on a calculated monthly tolerable load.

While some trace elements are essential plant nutrients at low concentrations, at high concentrations most of them become either toxic to crop growth or to humans or animals consuming the produce grown on such trace element enriched soils. Since trace elements tend to accumulate in soil, there is practically no safe level for sustainable irrigation on a continuous basis. The DSS calculates the time it would take for a trace element to accumulate to a protective accumulation level in soil, as indicator of the acceptability of trace element concentrations in irrigation water. Accumulation up to the threshold load within a period of 200 years or longer is considered ideal, while periods of less than 100 years are considered unacceptable.

Suitability indicators of crop yield and quality

The effect water constituents have on crop yield is mostly indirect, in that crop yield is affected by the constituent concentration in the soil. Six suitability indicators are used in this regard, namely the EC, B, Cl and Na concentrations in the root zone, as well as nutrient and pesticide contents. Three suitability indicators are directed at quantifying the effects on crop quality, namely leaf scorching by Na and Cl, microbial contamination of crops and nutrient effects.

The presence of **salts within the root zone** reduces crop growth by reducing the ability of plant roots to absorb water from soil. It is convention to measure and express the root zone salinity of soil as ECe (Electrical Conductivity of a saturated soil extract). In addition to EC, crop growth is also affected by the accumulation of **B, Cl and Na in the root zone.** The effects of the latter three constituents are deemed to be of a toxic nature, since their effect on yield reduction is more pronounced than would be expected from the equivalent EC concentration in the root zone. A large body of data is available that links yield response of different crops to soil EC and concentration of B, Cl and Na in the root zone. This body of data is used by the DSS as crop specific parameters to assess the effect of EC, B, Cl and Na in the root zone on crop yield.

Crops that are **susceptible to foliar damage** (which affect crop quality) when salts are absorbed directly through their leaves, often display greater yield reductions than when only exposed to root zone effects. However, almost no quantitative data are available which quantify this effect on yield and only limited qualitative data are available to assess the relative susceptibility of crops to foliar injury. The DSS therefore evaluates the degree of leaf scorching experienced by crops for which data are available, only in qualitative terms, and only when the selected irrigation application method allows for foliage to be wetted.

The presence of **plant nutrients** in irrigation water is mostly considered as an advantage, since it represents a potential saving in fertiliser costs. However, the presence of nutrients may also complicate fertiliser management, as high concentrations may stimulate excessive vegetative growth and cause lodging, delayed crop maturity and poor quality. The approach adopted for evaluating the presence of plant nutrients in irrigation water is to estimate both the quantity of NPK that will be added through irrigation and the contribution their addition will make to the NPK removed by a specific crop. The assessment of fitness for use is based on the contribution that irrigation applications makes towards the estimated NPK removal by crops (indirectly the crop nutrient requirement). When inadvertent nutrient additions through irrigation are relatively low compared to crop requirement, it is relatively easy to accommodate the additional nutrients as part of normal nutrient management practices, and the additional nutrients may be viewed as beneficial. However, as inadvertent nutrient additions increase, it becomes increasingly difficult to manage the negative effects associated with unintended higher fertiliser applications.

The main concern about the presence of **human pathogens** in irrigation water is the risk posed to food safety (crop quality) when crops destined for human consumption are contaminated during irrigation. The deposition of pathogens during irrigation is of particular concern for fruit and vegetables which are consumed raw, or which undergo minimal processing. The levels of *E.coli* are used as an indicator of microbial pathogens, and more specifically Norovirus, in irrigation water. Norovirus is recognized as the most common agent of viral diarrhea transmitted by irrigation water and by irrigated fresh produce consumed raw. The risk of norovirus infection per person per year is estimated using a dose-response look-up table, which gives the risk of norovirus infection per person per year when consuming lettuce irrigated with water of different *E.coli* concentrations. The calculated risk of exposure is thus based on the total annual *E.coli* intake. For crops other than lettuce, the annual intake is calculated from the volume of irrigation water retained by the crop and how much of the crop is consumed on an annual basis, relative to that of lettuce. Whether a crop is wetted by irrigation and the volume of water retained, is determined by the irrigation system and anatomy of the crop. The DSS output reports the risk of infection as the number of excess infections per thousand persons per annum (p.a.).

From a review of available information, it was clear that the **pesticide concentrations** measured in water resources are low and that the likelihood is small for irrigation water to be the source of unacceptable pesticide residues on produce. Herbicides are the most widely applied class of pesticides in South Africa. In view of the phytotoxic risk they pose to non-target/sensitive crops, herbicides are more likely to be of concern to irrigation farmers. Although this risk also appears to be low based on available evidence, it was decided to include herbicides as one of the suitability indicators in the DSS. After glyphosate, atrazine is the most widely used herbicide in South Africa. Since atrazine is highly mobile compared to glyphosates, with a significantly longer half-life, it was selected for inclusion in the DSS.

Atrazine is used to control annual broadleaf weeds and certain grasses in maize, grain sorghum and sugarcane, as a pre- and/or post-emergence application. A problem associated with atrazine applications (and thus with atrazine applications through irrigation) is that the residual atrazine remaining in the soil may damage atrazine sensitive follow-on crops. The DSS calculates the atrazine dosage applied through irrigation and uses international criteria to assess a qualitative risk this dosage poses to sensitive crops. The dosages recommended by manufacturers are used to assess the qualitative risk posed to maize, grain sorghum and sugarcane.

Suitability indicators of the effect on irrigation equipment

Irrigation water is normally supplied untreated. It is thus not chemically stabilised to control the potential for corrosion or scaling of irrigation equipment or filtered so that it can be used directly for drip irrigation. Corrosion and scaling of irrigation equipment and structures are arguably the primary water quality problems associated with on-farm irrigation infrastructure. Either can necessitate the early replacement of expensive irrigation equipment. Both corrosion and scaling are the result of waters having chemical imbalances. A secondary problem associated with water constituents is the clogging of drippers, which can be of a chemical, biological or physical nature.

The **prediction of corrosion** and scaling is a complex phenomenon with several factors determining its outcome, some of which are very site-specific. Although minor scaling which forms a protective layer against corrosion inside pipes is normally considered beneficial, excessive scaling reduces flow rates and damages water systems, necessitating repair or replacement. The most common cause of scaling is the precipitation of calcium carbonate when its saturation is exceeded. Although less frequent, gypsum precipitation also occurs in irrigation equipment when water high in calcium and sulphate is used.

The DSS uses the Langelier Saturation Index (LI), which is an approximate measure of the degree to which water is saturated with calcium carbonate, as indicator of the likelihood of corrosion or scaling. A positive LI indicates that water is over-saturated, and scaling is likely, while a negative LI indicates water is under-saturated with respect to calcium carbonate and is potentially corrosive. The DSS uses the LI to determine the corrosion or scaling potential of a water sample.

The low flow rates in drip emitters are conducive to **clogging problems**. While it is relatively easy to spot blocked openings, it is very difficult to identify openings that are partially blocked. Both alter the hydraulics of the entire system, result in a decrease in the uniformity of application and give rise to reduced yields. The DSS use criteria gleaned from literature, to assess the potential of several water constituents to cause clogging problems in drip irrigation systems.

Conclusions

This paper described the suitability indicators that are used in the newly developed electronic Decision Support System (DSS) that assists users to assess the fitness for use of irrigation water. The identified suitability indicators provide the means whereby those sub-components of soil quality, crop yield and quality, and irrigation equipment that are likely to be affected under irrigation with a specific water, can be identified and the significance of the effect quantified. A more in-depth account of suitability indicators and criteria used, have been described by du Plessis et. al., 2017.

Electronic copies of the DSS can be downloaded from:
https://www.nbsystems.co.za/downloads.html

Please send comments and feedback to ***meiringd@gmail.com***

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