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Too wet, too acid, too saline?

Plants to modify the watertable - The role of shrubs and woody forbs

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Summary: Experiments on typical mallee soils were established to monitor soil moisture use and groundwater recharge under different landuse practices using either annuals (cereals and pastures) or woody perennials (mallee and jojoba). Patterns and degree of soil moisture utilisation differed significantly between treatments as well as with time. The pattern of water use by cereal crops was less than the pasture species, but woody perennials had a greatest capacity to utilise soil moisture and to a much greater depth in the profile. The rate of groundwater recharge at depth diminished with time under perennials compared with annuals. At 200 cm, flux rates of around 0.035 mm/day or approximately 11 mm of recharge per year were maintained under fallow or cereals, but this fell to 0.01 mm/day (or approximately 2.0 mm/yr) beneath the perennials. The data shows that the cropping phase of traditional farming is the worst at minimising recharge with medic, lucerne, jojoba and mallee becoming increasingly effective.

Clearing native vegetation has been shown to cause significant increases in groundwater recharge, ultimately leading to dryland salinisation through rising watertables. There have been a number of studies which have shown how recharge rates have been increased by clearing native vegetation and imposing "European" agriculture in a semi-arid environment. However, few studies have evaluated the effect of different post-clearing land uses on recharge. O'Connell *et al.* (1995) showed that fallowing typical mallee soils increased recharge rates by as much as 56 mm/yr. Cook and Walker (1990), identified the importance of soil texture in controlling recharge. They measured recharge of less than 10 mm/yr in soils with more than 20% clay, but in sandy soils recharge could be as high as 50 mm/yr. They also concluded that drainage 50 cm deep in the soil occurred in response to rainfall events and that during summer larger rainfalls were needed to cause recharge than during winter. Eliminating fallow and the periodic growing of deep rooted perennials has been suggested as a possible means of reducing recharge in mallee soils (O'Connell *et al.* 1995).

Very few studies have measured soil water flux in sufficient detail to understand the mechanisms by which recharge occurs and allow the evaluation of vegetative means for dampening of recharge.

This paper presents data from a five year field experiment located near Hillston, in central-western NSW to illustrate the impact of landuse on soil water dynamics and groundwater recharge.

Methodology

Site description

The experimental site (33° 23'S, 145° 50'E; elevation 145 m ASL) was located on aeolian deposits overlying Devonian sandstones at the northern extremity of the Lachlan range and in the north-east of the Murray Basin. It has a slight slope of 0.3% and a north-eastern aspect. The soil is a calcareous red earth (Stace *et al.*, 1968) with a Northcote classification of Gn 2.13 (Northcote, 1971). The experiment was established on land which had been "cleared" of trees (white cypress pine, mallee, bull oak and western red box) in 1988. Dryland wheat crops were grown on the site during 1989 and 1990 and the site was ploughed and levelled during 1991 in preparation for the experiment.

Experimental design and layout

Four farming systems were established, two using perennial shrubs and two using cropping and pasture rotations. The cropping treatments were established as a cyclical rotational experiment (Patterson 1963). Each phase of the eight year rotation was expressed every year providing an efficient means of replication in both time and space. Spatial variability of soil properties, initially assessed by electromagnetic survey (Geonics EM38), was considered in final layout design.

The experimental area was divided into 25, 40 m x 40 m plots. All agronomic and soil water measurements were made in a 10 m x 10 m central sub-plot with the remainder of the plot serving as a buffer. Cropping and pasture treatments were allocated to sixteen plots; eight to a traditional rotation of crop and annual pasture (fallow, oats, wheat x 2, medics x 4), and eight to a modified rotation where lucerne replaced the medic. A further four plots were planted to blue mallee [5 000 plant /ha, planted in 2 m rows, plants 1 m apart within the row] and the remaining five to jojoba [1 000 plants /ha planted in 5 m rows, plants 2 m apart within the row]. The mallee and jojoba plots were fenced to exclude stock and allow grazing of the remainder of the trial site whenever required. All the perennial shrubs were planted in October 1991, following a pre-plant irrigation of the entire experimental area in September, and a pre-plant herbicide application (2 kg [ai]/ha oxyfluorfen + 2 kg [ai]/ha oryzalin). Subsequent weed control on mallee plots was achieved by herbicide application of 1 kg [ai]/ha oxyfluorfen immediately after the first two harvests. No further weed control was needed on the mallee plots. Periodic inter-row cultivation and hand chipping was used to control weed growth in the jojoba plots.

The rotational treatments were established in the autumn of 1992 and four phases of the rotation grown until autumn 1996. Fallow was established in April and maintained until the crop was sown, usually 14 months later. Cereal and pastures were sown following the first suitable rainfall after the beginning of May. Broadleaf weeds were controlled as required using herbicides. Because of drought, the pasture plots sown in 1994 failed to establish and had to be resown the following year. All crop and pasture plots were grazed annually as one land unit at least once between harvest (December) and April.

Only data from five of the plots are presented here. One plot of each landuse (Table 1) has been selected to illustrate differences in soil water use and recharge.

Soils data

Soil moisture was monitored by neutron moisture meter from a single 4 m aluminium access tube located in the centre of each plot. The tubes were installed using the slurry method of Greecen (1981). The top section of the tubes were removable to allow unhindered cultivation. Soil moisture content was measured at 12 depths (10, 20, 30, 50, 75, 100, 125, 150.....350 cm) at fortnightly intervals, commencing November, 1991.

The hydraulic properties of each soil horizon were described by the Broadbridge and White (1988) model. The initial parameters of the model were developed by field measurement of the soil moisture characteristic, using the filter paper method (Greecen *et al.* 1987), and hydraulic conductivity, by disc permeametry (White *et al.*, 1992). These parameters were refined by trial and error inverse modelling (Hume and Mitchell, 1996).

Soil water flux

The soil water flow between two points in space and time was calculated by Darcy's Law using soil matric potential (Ψ), total potential (h) and unsaturated hydraulic conductivity (k_θ) profiles. Soil matric potential (Ψ) and hydraulic conductivity were predicted from the measured profiles of soil moisture content (θ) using the Broadbridge and White soil model (Hume *et al.* in press).

Agronomic data

Germination and establishment of all traditional crops and pastures were measured using standard methods. Biomass of cereals was assessed at anthesis by weighing all above ground plant material after drying at 75°C for 24 hrs or until no further weight loss. Grain yield was assessed using quadrat cuts at maturity as well as by harvesting each plot with a header. Pasture biomass was determined by regular clipping (0.1 m^2 quadrats) throughout the growing season.

Above ground biomass and oil yield of blue mallee was measured each August by cutting and weighing plants for biomass then distilling subsamples of leaf for oil content (Milthorpe *et al.* 1994). Jojoba production was estimated by measuring plant height and applying a known

Table 1. Production data for Hillston (t DM/ha).

Year	Cropping	Pastures		Mallee	Jojoba
		Annual	Perennial		
1992-3	0.00^F	6.51^W	6.56^W	5.53	0.09
1993-4	12.67^O	5.80^M	1.21^L	3.96	0.23
1994-5	0.00^W	0.00^M	0.00^L	1.20	0.48
1995-6	6.10^W	0.89^M	0.82^L	1.03	1.68

^{F}Fallow; ^{L}Lucerne; ^{O}Oats; ^{W}Wheat; ^{M}Medic.

relationship between plant height and weight. Jojoba seed yield was measured each year from March 1995 and included in biomass estimates.

Climatic data

Net radiation, soil and air temperature, relative humidity and rainfall were recorded hourly by an automatic weather station. Rainfall was also recorded manually.

Results and discussion

Above average rainfall was experienced during 1992 and 1993. The spring of 1993 was extremely wet with near record registrations recorded for July, September, October and December. This was followed by drought during 1994 and an average pattern of rainfall in 1995.

Crop growth

The biomass yield from each of the four selected plots is presented for four years of the trial (Table 1). Mallee production was assessed each August at harvest whereas all other plots were assessed from April to March. Because of this, plus the fact that mallee is dormant from June until harvest it was necessary to adjust the data to match the other treatments. During the 1994-95 year production from all plots was extremely low except for jojoba which had a low but steady increase in production. Drought conditions coupled with uncontrollable rabbit grazing precluded any meaningful production measurements being made from the cereal and pasture plots during 1994-95. Generally cereal and pasture production reflected district trends.

Soil moisture changes

Soil moisture beneath the cropping sequence of fallow, oats, wheat, wheat (Figure 1a) shows little change for the duration of monitoring. The pasture sequence of wheat, medic, medic, medic, medic (Figure 1c) produced a slow but progressive decline in subsoil moisture during the first four years, after which time it remained stable. The data for the modified pasture sequence of wheat, lucerne, lucerne, lucerne (Figure 1b) show little change in soil moisture levels until mid-October [about day 700] of the first year of lucerne. At this time there was a rapid decline in the soil moisture content of the top 75 cm of soil. This can be attributed to water use by active plant growth.

Soil moisture content fell rapidly under mallee (Figure 2a). This decline commenced earlier than under any other treatment and to a greater depth. Mallee is quick to establish and grow and maintained production throughout the experiment, and the soil beneath the mallee remained consistently dry. However, the soil beneath jojoba remained relatively wet during the first two years, but during the third year [about day 1100] soil moisture content began a rapid decline. This reflected the pattern of above ground production of widely spaced (1 000 /ha) jojoba plants which produce little vegetative material until the third year (Figure 2c).

Recharge rates

Under the cropping phase of the traditional farming system, the rate of recharge at 200 cm remained constantly high for the duration of the trial (Figure 1b). The drought of 1994 had only a minor effect on recharge at this depth with a slight reduction during late 1994 and early 1995. The recharge rates increased again with the normal rains of 1995. Initial recharge rates at 75 cm were similar to those at 200 cm and attributed to the 1991-92 fallow. Following the establishment of an oat crop in 1992 the rates at 75 cm decreased to minimal levels. However, large pulses of recharge occurred in the spring of 1993; the winter of 1995 and the winter of 1996.

There is a contrasting pattern in the rate of recharge beneath four years of medic pasture grown after wheat (Figure 1d). The rate at 200 cm declined steadily from 0.05 mm/day in December 1991 (similar to that beneath wheat) to almost zero by December 1996. Inputs to the deeper soil were minimal as drainage at 75 cm was low even except for a pulse of drainage during 1993-94, the establishment year of medic.

Where wheat was followed by four years of lucerne some recharge occurred below 75 cm in the first year under wheat and during the second year before the lucerne became established (Figure 1f). At 200 cm, drainage continued as recharge rates remained high until the spring of 1993 when the established lucerne stand started to use significant amounts of water.

Recharge at both depths (75 and 200 cm) under mallee had almost ceased by mid-1992 and continued to be very low for the rest of the monitoring period (Figure 2b), showing the ability of this deep rooted, quick growing plant to extract moisture from deep in the profile and then intercept any further rainfall. There were short periods of increased recharge, in the spring of 1992 at 75 cm depth, and the spring of 1993 at 200 cm deep. These 'episodes' coincided with high rainfall when the mallee were at an early stage of post-harvest regrowth.

The highest recharge rates were measured beneath jojoba. Recharge at 75 cm consistently exceeded that at 200 cm until the end of 1993. At this time recharge at 75 cm declined from 0.06 mm/day to almost zero in two months and established a new equilibrium rate of about 0.01 mm/day. Recharge at 200 cm declined but more slowly from 0.07 mm/day in April to a new equilibrium of 0.01 mm/day by March 1995. These patterns reflect the development of jojoba (Figure 2d). Each winter,

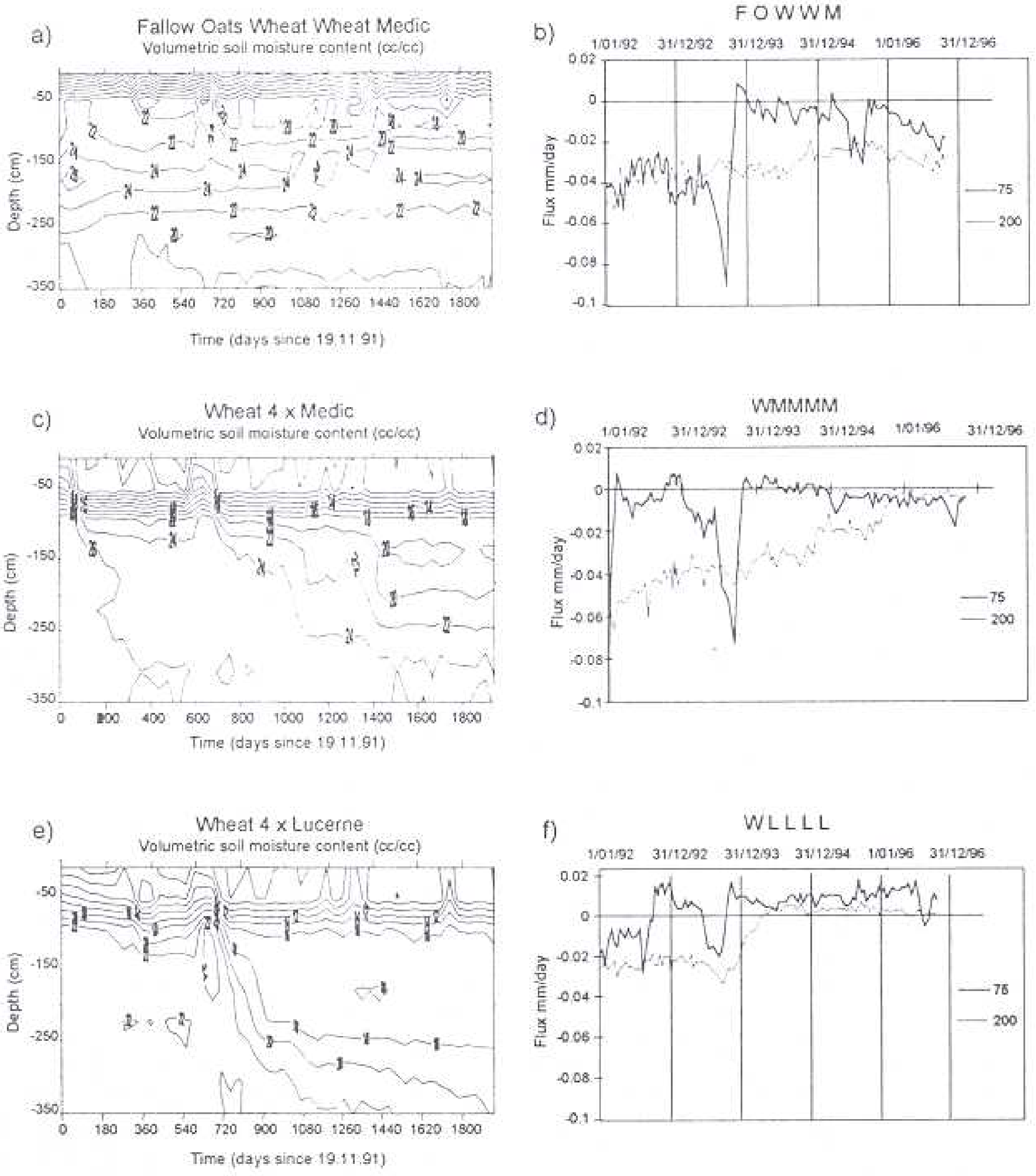

Figure 1. Soil moisture and flux rate changes over a five year period for one cropping and two pasture phases of a rotation, grown on mallee soils.

when jojoba is dormant, there is a small increase in the recharge rate at 75 cm but this does not appear at 200 cm and jojoba has the ability to utilise all this moisture before it can pulse to 200 cm.

It is important that the above data be viewed in context of what has happened since clearing in 1988. Detailed soil moisture data was not collected from the site prior to clearing, hence no record of initial soil moisture profiles are available. However, at the commencement of the study, the soil sampled to a depth of 3.9 m beneath nearby timbered land was dry throughout the profile (data not presented). Consequently, a large build-up of soil moisture had occurred during the period from clearing in 1988 to the commencement of the trial in 1991. During this time the land was fallowed for one year, cropped for two and fallowed one more before a pre-irrigation.

The initial high recharge rates measured under all plots reflect this build-up of soil moisture and it has only been under the deep rooting perennials that the recharge has been reduced to levels similar to that which occurred pre-clearing.

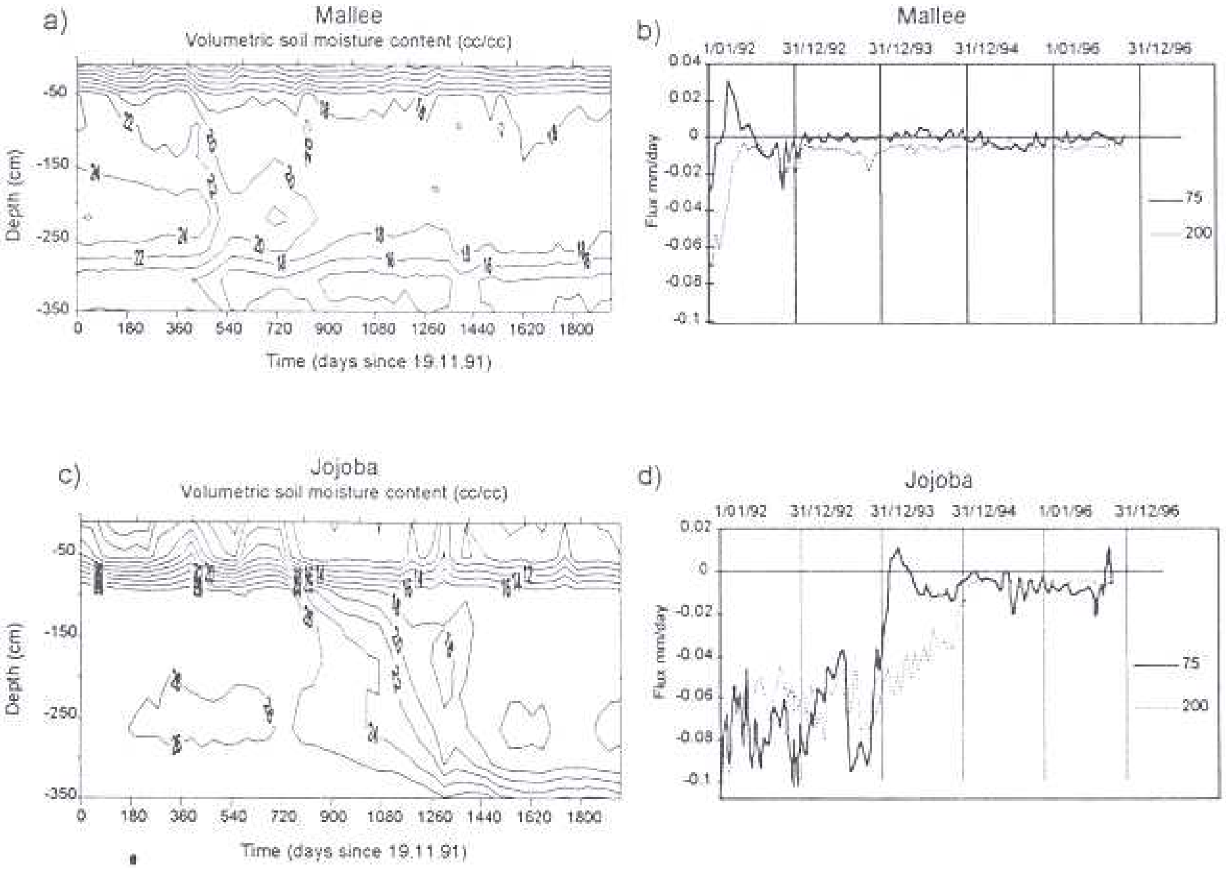

Figure 2. Soil moisture and flux rate changes over a five year period for mallee and jojoba, grown on mallee soils.

The take home message is that to prevent recharge at 2 m we must first provide a buffer for rainfall, by having a dry topsoil, and second, use all the water from that part of the profile by transpiration. The work at Hillston shows that the cropping phase of traditional farming is the worst at achieving this, with medic, lucerne, jojoba and mallee becoming increasingly effective.

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