Soil fertility indicators for the cotton-growing region of the Lower Namoi Valley

Inakwu Odeh, Eugenia Figueroa and Alex. B. McBratney
Australian Cotton CRC, Dept. of Agric. Chem. & Soil Science, The University of Sydney

Introduction

Soil fertility is the most important soil quality indicator that needs to be measured and monitored. Through human history, decline in soil quality in general, and fertility in particular (due to neglect) had led to the demise of Great Empires. Recently, soil quality and its importance has received extensive attention due to environmental concerns. Soil quality has now formed the basis for the development of sustainable agriculture, and indeed it could be used for evaluating and judging the sustainability of soil management practices and land use systems (Wang and Gong, 1998).

Soil fertility can be defined as the capacity of the soil to supply nutrients and provide other physical and chemical conditions for optimal crop growth. Soil fertility, therefore, is a subset of soil quality, which defines the overall fertility and the soils capacity to sustain crop production, provide good conditions for soil organisms, imbibes and ameliorate environmental pollution and resist degradation (Larson and Pierce, 1994). The focus of this paper is on the analysis of chemical fertility and its versatility and distribution patterns in the lower Namoi Valley. In doing so, we emphasize the basic soil (chemical) fertility and its generality and are not specific to any particular crop. The principle is, however, relevant to the dominant crops grown in the area, namely: cotton, wheat and sorghum.

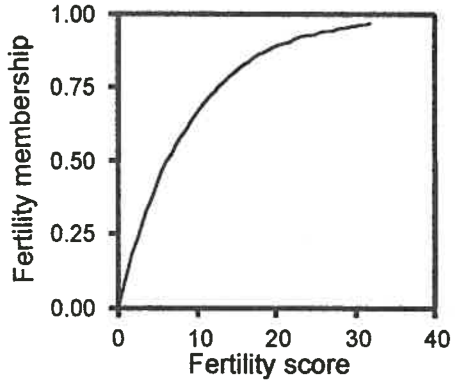
Table 1. Fertility scores for selected soil properties as indicators

Indicator	Range/Rules	Fertility	Score	Indicator	Range/Rules	Fertility	Score
pH	$6.5 \le pH \le 7.5$ $5.5 < pH < 6.5$ or $7.5 < pH < 8.5$ $pH < 5.5$ or $pH > 8.5$	optimal possible unlikely	27 9 3	**ESP %**	$ESP \le 6$ $6 < ESP \le 14$ $ESP > 14$	optimal possible unlikely	27 9 3
CEC mmol/kg (+)	$CEC > 250$ $120 \le CEC \le 250$ $CEC < 120$	optimal possible unlikely	27 9 3	**EC dS/m**	$EC \le 2$ $2 < EC \le 14$ $EC > 14$	optimal possible unlikely	27 9 3
Ca mmol/kg (+)	$Ca > 100$ $50 \le Ca \le 100$ $Ca < 50$	optimal possible unlikely	27 9 3	**P mg/kg**	$P \ge 24$ $12 < P < 24$ $P \le 12$	optimal possible unlikely	27 9 3
Mg mmol/kg (+)	$Mg > 30$ $10 \le Mg \le 30$ $Mg < 10$	optimal possible unlikely	27 9 3	**OM %**	$OM \ge 5$ $2 < OM < 5$ $OM < 2$	optimal possible unlikely	27 9 3
Na mmol/kg (+)	$7 < Na < 20$ $7 \le Na \le 3$ $Na < 3$ or $Na > 20$	optimal possible unlikely	27 9 3	**N %**	$N > 0.15$ $0.05 \le N \le 0.15$ $N < 0.05$	optimal possible unlikely	27 9 3
K mmol/kg (+)	$K > 20$ $3 \le K \le 20$ $K < 3$	optimal possible unlikely	27 9 3	**C/N ratio**	$10 \le C/N \le 15$ $15 < C/N < 20$ $C/N < 10$ or $C/N > 20$	optimal possible unlikely	27 9 3
Ca/Mg Ratio	$4 \le Ca/Mg \le 6$ $1 \le CaMg \le 4$ $Ca/Mg > 6$	optimal possible unlikely	27 9 3				

Materials and Methods

The study area is in the lower Namoi Valley near Wee Waa in northwestern NSW. The area is approximately 4200 km^2. The sampling design used was stratified simple random, with sites selected randomly from 14 strata. A total of 125 sites were visited and sampled at six depths: 0-10, 10-20, 30-40, 70-80, 120-130 and 190-200 cm, respectively. For the purpose of this analysis, only 0-10, 30-40

Figure 1. Membership function on the fertility scores



and 70-80 cm depths were used. Ten soil properties: soil organic matter (OM), pH, CEC, Ca, Mg, Na, K, P, N, EC, and the derivatives: ESP, Ca/Mg and C/N ratios were used for the analysis. These are all chemical fertility indicators. Each of the fertility indicators was analyzed based on a set of rules, for its optimal condition for crop growth. For example, rules for pH (in soil: water suspension) were: if $6.5 \leq pH \leq 7.5$ then the condition is optimal, if $5.5 < pH < 6.5$ or $7.5 < pH < 8.5$, then the condition is possible, and if $pH \leq 5.5$ or $pH \geq 8.5$ then the condition is unlikely. A set of all the rules used in the fertility scores and indicators are shown in Table 1. The rules for generating the fertility scores are by no means certain. They represent some ambiguities and vague terms used to describe the fertility scores. We therefore fitted a fuzzy membership function to the scores for each of the indicators, to gauge the degree of contribution to soil fertility by the indicators. The fertility membership grade, in each case is exponential function similar to the one used by Triantifilis and McBratney (1993):

$$\mu_I = e^{-0.109 F_I},$$

where μ_I is the fertility membership grade of indicator I, F_I is the fertility score of the indicator I. Figure 1 illustrates the membership function in relation to the fertility (indicator) scores. In this way, each of the indicators listed in Table 1 are transformed into membership grade of fertility. The fertility membership grade for each of the indicators for the three layers was mapped, using the geostatistical interpolation technique of kriging.

Results and Discussion

As an illustration of examples, Figure 2 shows the contour maps of the fertility grade for topsoil pH and available phosphorus. Both indicators show a mild limitation in terms of contribution to the soil fertility. In the case of the pH fertility grade map, the areas with less than 0.50 fertility grade is just east of Pilliga, which is the Pilliga Scrubland and east and northeast of Burren Junction. The parent rock of the soil of the scrubland is the Pilliga Sandstone, which had lost much of the basic nutrients during the process of rock formation and weathering. The relatively low fertility status of this area is evident for most of the indicators listed in Table 1. However, available P is hardly shown to be

Figure 2.

a) Contour map of membership that pH is optimal for crop growth

b) Contour map of membership that P is optimal for crop growth

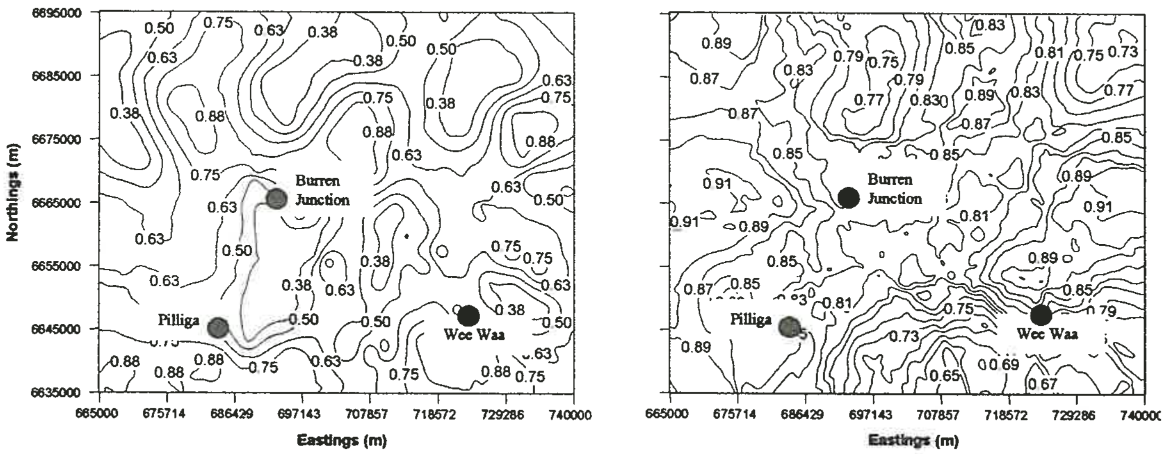
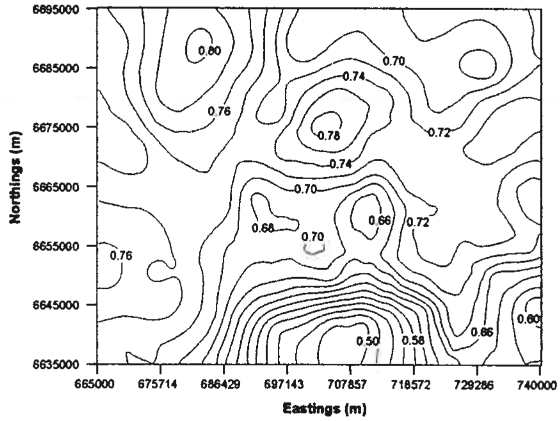
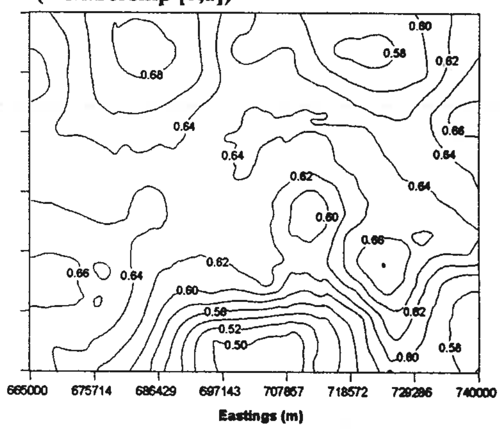


Figure 3.

a) Contour map of topsoil fertility versatility (membership [0,1])



b) Contour map of subsoil fertility verstility (membership [0,1])



limiting at all, although sampling at denser spacing would probably reveal some local patches of low P availability in the Pilliga Scrubland.

In order to gauge the overall soil fertility of each layer and the soil profile down to 80 cm depth, we derived fertility versatility, a measure of how fertile a soil is with respect to all the indicators used. In other words, how amenable is the soil fertility in respect of many fertility indicators that contribute to the overall soil fertility? To answer this question we calculated the averages of the membership grade of the entire indicators for a given layer as fertility versatility for that layer at site *i*, using the expression:

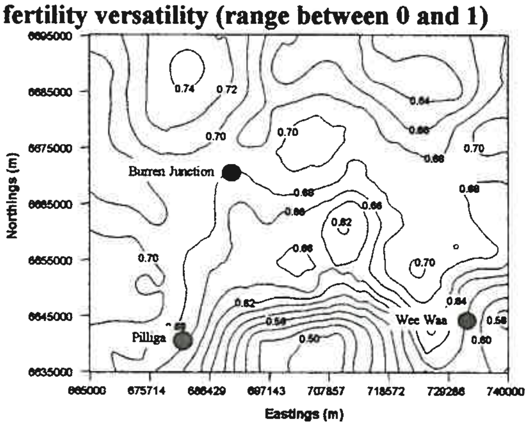
$$F_{Vl} = \frac{1}{p}\sum_{k=1}^{p} \mu_{kl},$$

where F_{Vl} is the fertility versatility for layer l, μ_{kl} is the membership grade of indicator k for layer l, and p is the number of fertility indicators. To obtain the profile (0-80 cm depth) fertility versatility, we calculated the averages of the 3 layers as:

$$F_{V0-70} = \frac{1}{3}\sum_{j=1}^{3} \mu_{ij},\ i=1..n$$

The results of the layer fertility versatility are illustrated in the contour maps shown in Figure 3a for the topsoil and Figure 3b for the subsoil. Like the cases for the pH and P indicators, the layer fertility versatility is quite high for the study region, as the values hardly fall below 0.50. The only exception is the Pilliga Scrubland area, which shows versatility values below 0.50. The profile versatility (Figure 4) shows similar patterns. This shows that the contribution to the soil fertility by each indicator influences the overall versatility. Limitations by one or more of the indicators flows on to affect either the layer or profile (0-80 cm) versatility. On the whole the study area is very fertile based on the indicators used for our analysis. It is not surprising that the small section of the Pilliga Scrubland, east of Pilliga is used mainly for grazing or is part of the Pilliga State Forest.

Figure 4. Contour map of profile (0-80 cm) fertility versatility (range between 0 and 1)



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