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Statistical Modelling of Nitrogen Fertilizer Value of Different Manure Types in Crop Rotation

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Abstract: Six crops (wheat, soya bean, clover, cotton, faba bean and maize) were grown in succession at Ain Shams University farm, Shalakan (26 km north of Cairo), to assess the nitrogen fertilizer value of different manure types in crop rotations under warm climates. The trial was arranged in a factorial design to test the effects of manure type (raw sludge, digested sludge and FYM), manure rate (0, 5, 10, 20 m^3 fd^{-1}) and four N fertilizer application. Yield data from the trials were screened initially by ANOVA to determine the importance of these different experimental factors on crop performance and the significance of interactive effects between the treatments. The numerical parameter values of the statistical models describing yield responses to N fertilizer and the total N addition in the different manure types were used to derive N Fertilizer Equivalency values for the manure products. The results showed that the clearest picture of N availability for the different manures was obtained for the first crop of the rotation (wheat, winter season). This gave an N equivalency for digested sludge of 50 %. The results also show that the apparent N equivalency of raw and digested sludge increased as the trial progressed associated with the effects of cumulative additions of sludge on soil fertility and crop yields. The N equivalencies estimated for FYM were less consistent than for composted sludges, however, the N equivalency value calculated for FYM was apparently much larger than for sludge with some crops.

Key words: Field crops · N equivalency · Rotation sludge

INTRODUCTION

The newly reclaimed soils in Egypt are characterised by low fertility and poor moisture retention. Since animal manure is no longer readily available, other materials such as sewage sludge should be tested and used to meet soil nutrient and organic matter requirements. Sludge use in agriculture is widely regarded as the best practicable environmental option but is untested under Egyptian conditions [1]. Biosolids, is one of the most widely used organic wastes for this purpose [2]. Several studies have demonstrated its efficiency in increasing crop productivity, among them Tejada *et al.* [3], using sewage sludge treated as a source of nutrients for maize, reaching yields of up to 17 Mg ha^{-1} (~283 sc ha^{-1}) when applied together with mineral fertilizer. The sewage sludge is generally rich in organic matter, macro and micronutrients, suggesting the possibility of its use in agriculture as fertilizer and soil conditioner. However, unhygienic sewage sludge may present problems related to pathogens and heavy metals. Depending on their composition, their characteristics may limit their employment in agriculture. Although the concentration of heavy metals in this study has not been evaluated, the results of low productivity may be correlated with the accumulation of toxic elements in plants. According to Singh and Agrawal [4] municipal sewage sludge is highly abundant in the relevant components for soil fertilization and plant nutrition. These properties determine the advisability of sludge utilization as fertilizer, especially for the soils in Poland [5, 6].

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MATERIALS AND METHODS

Six crops (wheat, soya bean, clover, cotton, faba bean and maize) were grown in succession at the Ain Shams University farm, Shalakan (26 km north of Cairo), to assess the nitrogen fertilizer value of different manure types in crop rotations under warm climates applied in a conventional arable rotation of crops on Nile alluvium clay soil. Each experiment included treatments which were 4 nitrogen fertilizer levels presented in Table (1) and 24 combination of 4 raw, digested and farmyard manure levels *i.e.*; 5, 10, 15 and 20 m^3 fd^{-1} with and without reduced rate of N fertilizer (Table 1).

The experimental design in the trial was Complete Randomized Block Design with 4 replicates. Yield data and detailed indices of arable crop productivity were recorded throughout the field trials programme. The principal indicators of crop productivity were reported and the results have been subjected statistical analysis of variance (ANOVA) and means testing and the statistical significance of differences between treatment means has been assessed at the 5 % probability level. To define the optimum dressings of sludge and FYM for crop production a more dynamic modelling approach to describe yield effects and quantitative numerical descriptions of the relationships between crop yield and the amount of a particular input applied to the soil. Visual inspection of the data is necessary to decide whether linear or curvilinear, asymptotic or supra-optimal functions are the most appropriate.

The models used to describe arable crop yields take three basic numerical forms Cooke, [7] as follows:

linear model: $y = a + b_1x$ (1)

where y is the measured yield variable (units: t fd^{-1} or kg fd^{-1}); b_1 is the regression coefficient representing the linear gradient (or slope) of the incremental yield response to increasing application rate; x (units: kg fd^{-1}, t fd^{-1} or m^3 fd^{-1}) of the fertilizer or manure; and a is a constant value (intercept) representing the yield obtained without fertilizer or manure. The N fertilizer equivalency is calculated by dividing the regression coefficient for the manure, on the basis of its rate of total N application, with the coefficient obtained for the yield response to applied mineral N. The units quantifying the rate of N supplied to the soil are the same, kg N fd^{-1}, in both cases for the sludge and inorganic fertilizer.

curvilinear model: $y = A\ (1\text{-}b_2e^{-kx})$ (2)

Table 1: Nitrogen fertilizer treatments (kg N fd^{-1}) in the arable rotation trial on clay soil (Nile alluvium)

Rate	Wheat	Soya bean	Berseem	Cotton	Faba bean	Maize
1	30	15	15	25	15	60
2	60	30	30	40	30	75
3	75	45	45	55	45	90
4	90	60	60	70	60	105

Note: Values in bold denote the rates applied to sludge-amended treatments (reduced rate)

where y and x follow the notation in Equation (1); A is the asymptote value and represents the maximum potential crop yield; b_2 is a coefficient indicating the intercept value as proportion of A (given by 1 - b_2); and k is a constant which determines the rate at which y approaches the maximum yield A. In this case, the N fertilizer equivalency is determined by dividing the rate constant, k, for the manure with the constant for mineral fertilizer N.

supra-optimal model: $y = A\ (1\text{-}b_3e^{-kx}) - cx$ (3)

This model follows the same numerical form as Equation (2), but incorporates an additional parameter, c, that describes the linear reduction in yield from the maximum, sometimes associated with effects of excessive applications of nutrients on crop production.

The yield models were fitted to the data by linear or non-linear regression analysis techniques using the Costat computer programme (Cohort 6.3.1 Software) [8]. The non-linear regression analysis utilised a least-squares fitting procedure to optimise the numerical values of the model parameters. The final statistic to consider, which is given in the following figures of crop yield responses, is the coefficient of determination, r^2. This value provides a measure of the amount of variation explained by the model as a percentage of the total variability in the experimental data. The higher the r^2 value, the better since this shows that the model is providing as accurate a representation of the yield trend as possible. The N equivalency value was estimated according to [9].

RESULTS AND DISCUSSION

Inorganic N fertilizer always gave a positive yield benefit on clay soil and crop performance generally followed a linear pattern, except for soya bean, which produced a curvilinear response with increasing rate of fertilizer application (Figure 1). The results suggest that soya bean was more effective in utilising the applied fertilizer N than the other leguminous crops grown in the rotation, including faba bean and berseem, which

Table 2: Maximum yields (t fd^{-1}; mean values) obtained in the arable field trials

Crop	Maximum yield
Wheat (grain)	3.0
Maize (grain)	3.7
Faba bean	1.3
Soya bean	1.0
Berseem (FW)	12.0
Seed-cotton	1.2

Table 3: Results of 3-way ANOVA showing the statistical significance of effects of manure type and rate and N fertilizer application on the yield of different crops in a six season rotation on clay soil (Nile alluvium)

	Cropping type and sequence					
Source of variation	Wheat (grain)	Soya bean (seed)	Berseem (clover)	Cotton	Faba bean	Maize (grain)
Main effects						
Fertilizer (Fert.)	***	***	**	ns	ns	***
Manure rate (Rate)	***	***	***	ns	**	***
Manure type (Type)	***	***	***	**	**	ns
Interactions						
Fert. x Rate	**	ns	*	*	*	ns
Fert. x Type	*	***	**	*	ns	*
Rate x Type	**	*	*	**	*	***
Fert. x Rate x Type	ns	***	***	ns	ns	***

Note: Statistical notation: *, P<0.05; **, P<0.01; *** P<0.001; ns, not significant

Nitrogen fertilizer equivalency values for the sludge products and FYM

Table 4: Nitrogen equivalencies of raw and digested sludge, relative to inorganic fertilizer, for different crops on clay soil (Nile alluvium).

	Cropping season and type					
Manure type	Wheat (grain)	Soya bean (seed)	Berseem (Clover)	Seed-cotton	Faba bean	Maize (grain)
Raw	21	52	25	18	45	79
Digested	50	42	27	67	81	-
FYM	54	161	49.1	33	47	-

Note: [(1)] Equivalency not determined for digested sludge or FYM as yield responses to these materials were non-linear compared with inorganic N (Figures 1, 3 and 4)

produced linear yield patterns. The optimum dressings of N fertilizer for crops grown on clay soil are shown in Table (2). These compare closely to the rates of N recommended for arable crops (Table 1). Furthermore, maximum yields obtained in the trials (Table 2) were similar to, or greater than, the averages for typical Egyptian although these usually related to the sludge or farmyard manure treatments. Specific details can be found for the crops in the Progress Reports of the Study (10).

The effects of manure type (raw sludge, digested sludge and FYM), manure rate (0, 5, 10, 20 m^3 fd^{-1}) and N fertilizer application on economic yield of the tested field crops are presented in table 2. Yield data from the trials were screened initially by ANOVA to determine the importance of these different experimental factors on crop performance and the significance of interactive effects between the treatments. As expected, the main effects of the experimental variables were highly significant ($P < 0.01$ or $P < 0.001$) for most crops. Yield responses to increasing rates of the different manures, applied without N fertilizer, are presented in Figures 2, 3 and 4 for raw and digested sludge and FYM, respectively. The different approaches to modelling the yield patterns are also shown in the figures, which were generally consistent with the increases in yield observed for N fertilizer. Raw sludge and FYM generally followed the patterns obtained with N fertilizer, but digested sludge reduced the yield of seed-cotton and faba bean at the highest rate of addition.). The results suggest that soya bean was more effective in utilising the applied fertilizer N than the other leguminous crops grown in the rotation, including faba bean and Berseem, which produced linear yield patterns. The responses of a wide range of field and fruit crops to sludge application were found to be consistent with international experience, with enhanced plant growth and economic yield due to the supply of nutrients and trace

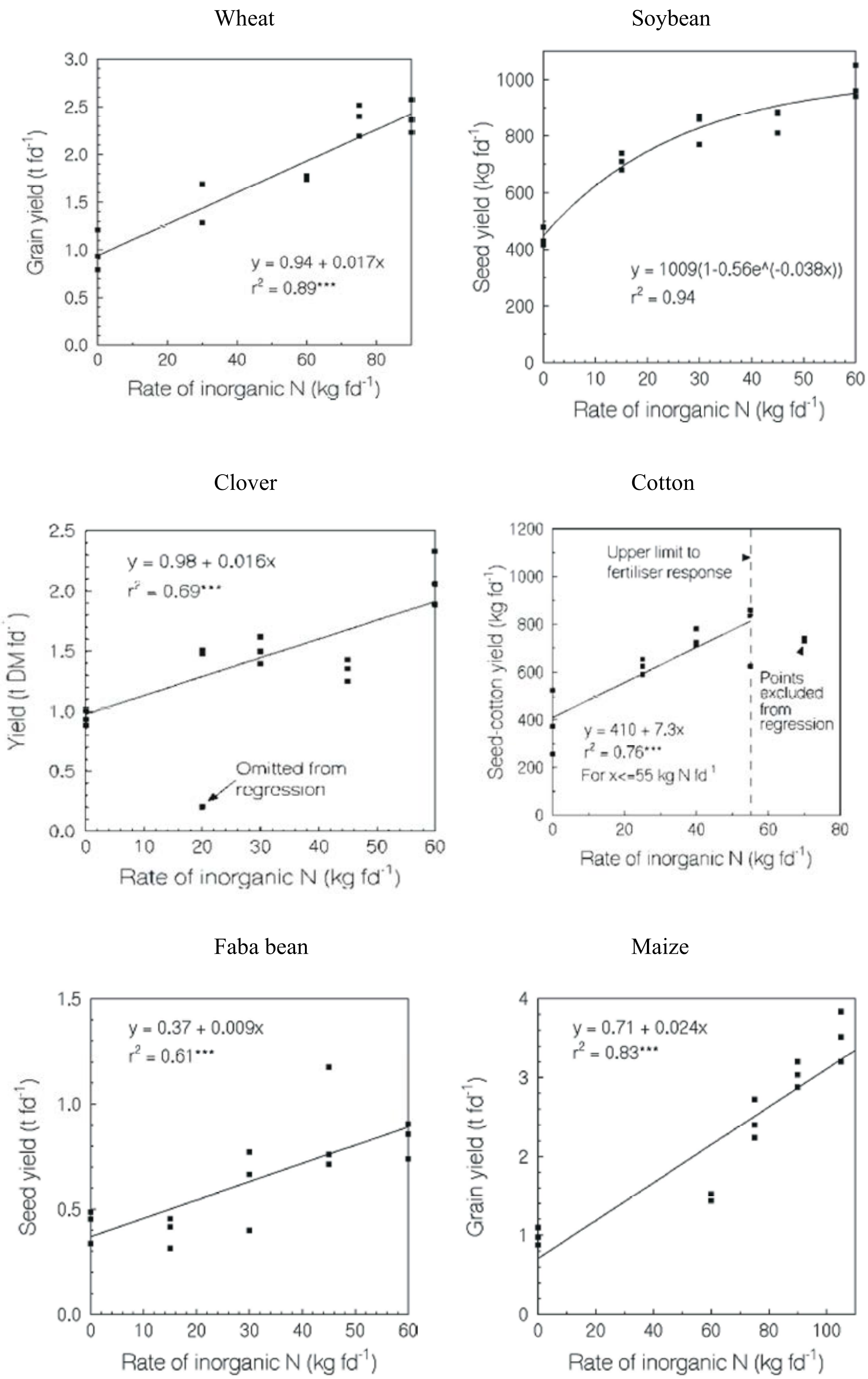

Fig. 1: Yield responses of different crops in a six season rotation in relation to the rate of inorganic N fertilizer application on clay soil (Nile alluvium)

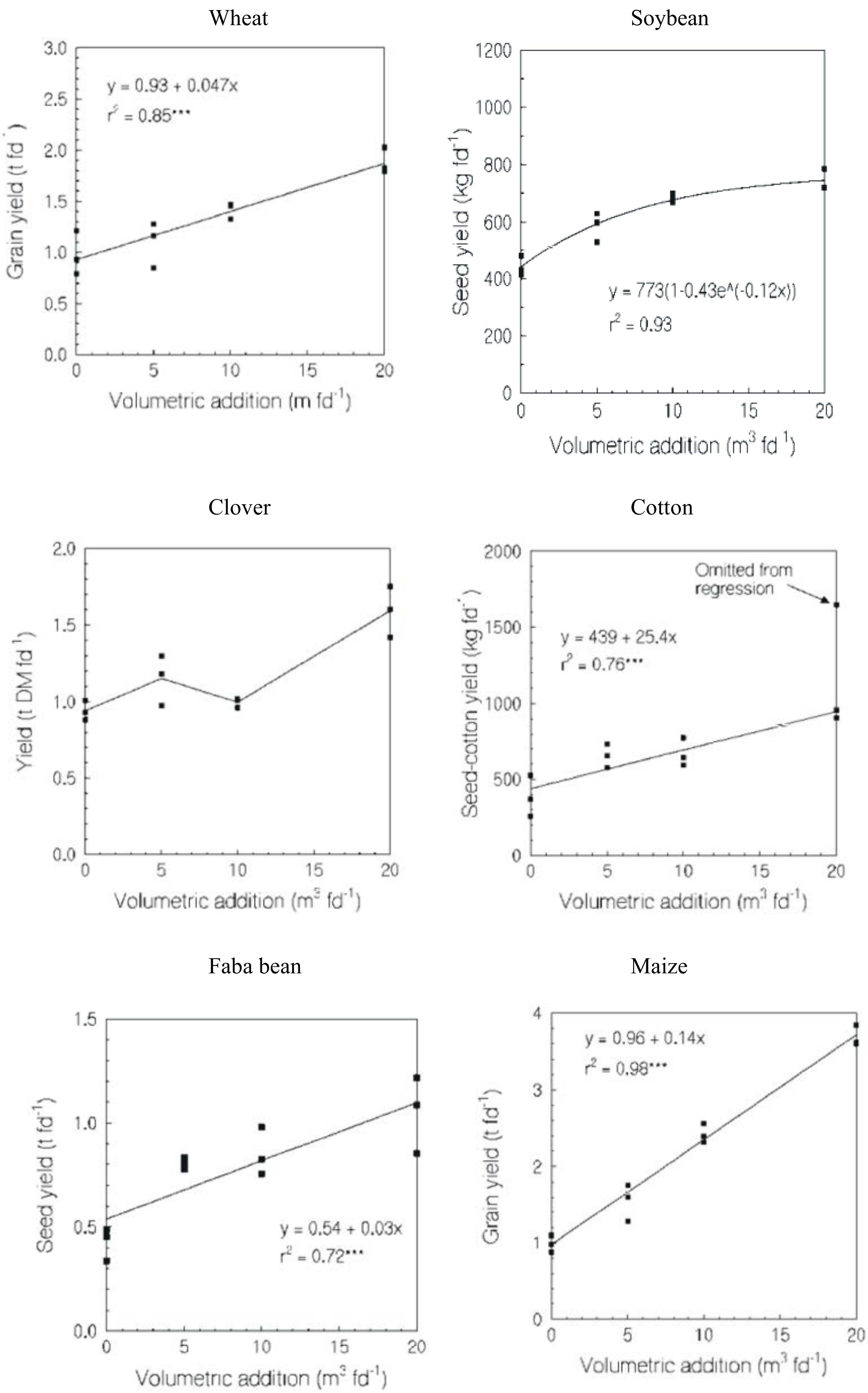

Fig. 2: Yield responses of different crops in a six season rotation in relation to volumetric additions of raw sludge to clay soil (Nile alluvium)

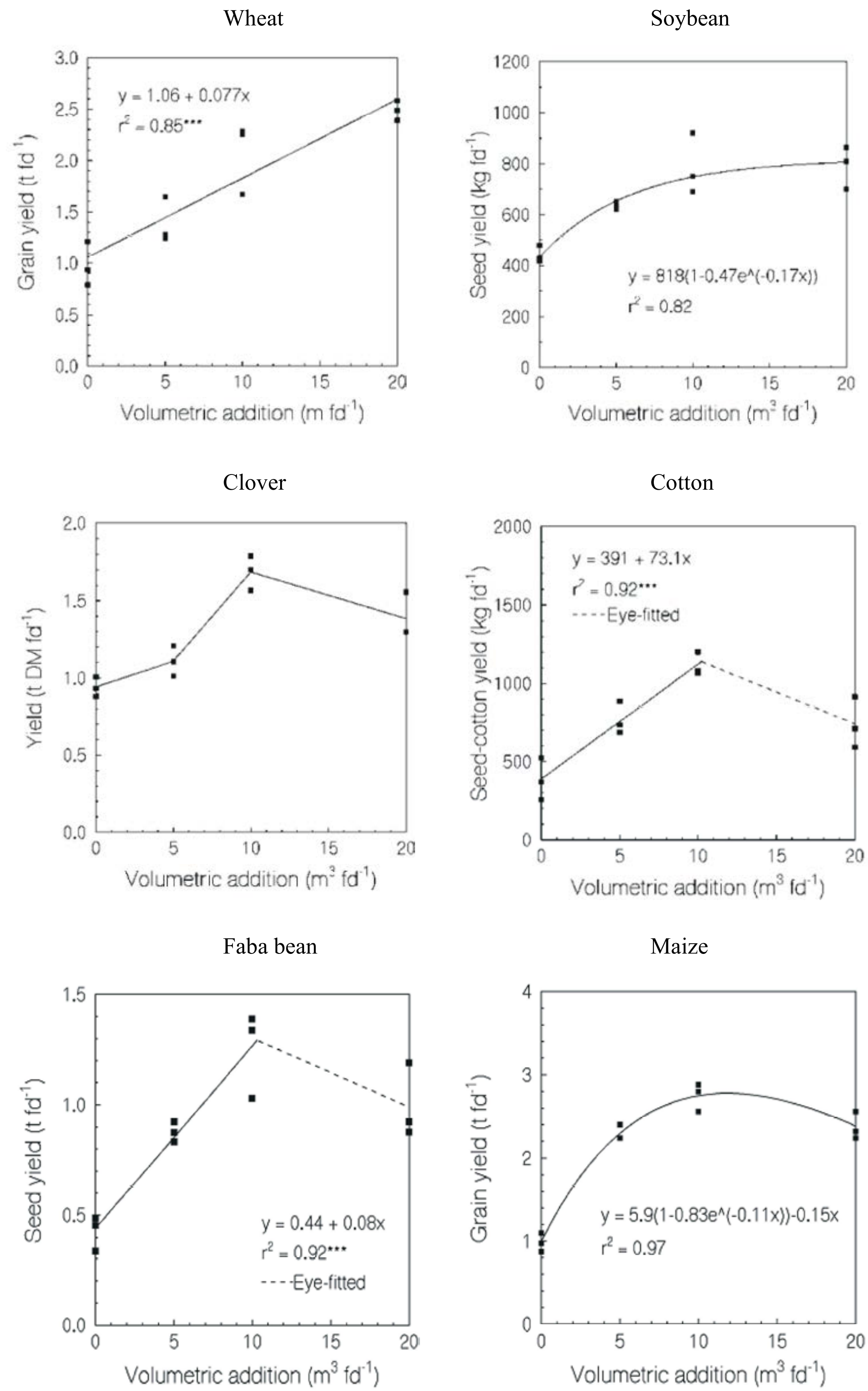

Fig. 3: Yield responses of different crops in a six season rotation in relation to volumetric additions of digested sewage sludge to clay soil (Nile alluvium)

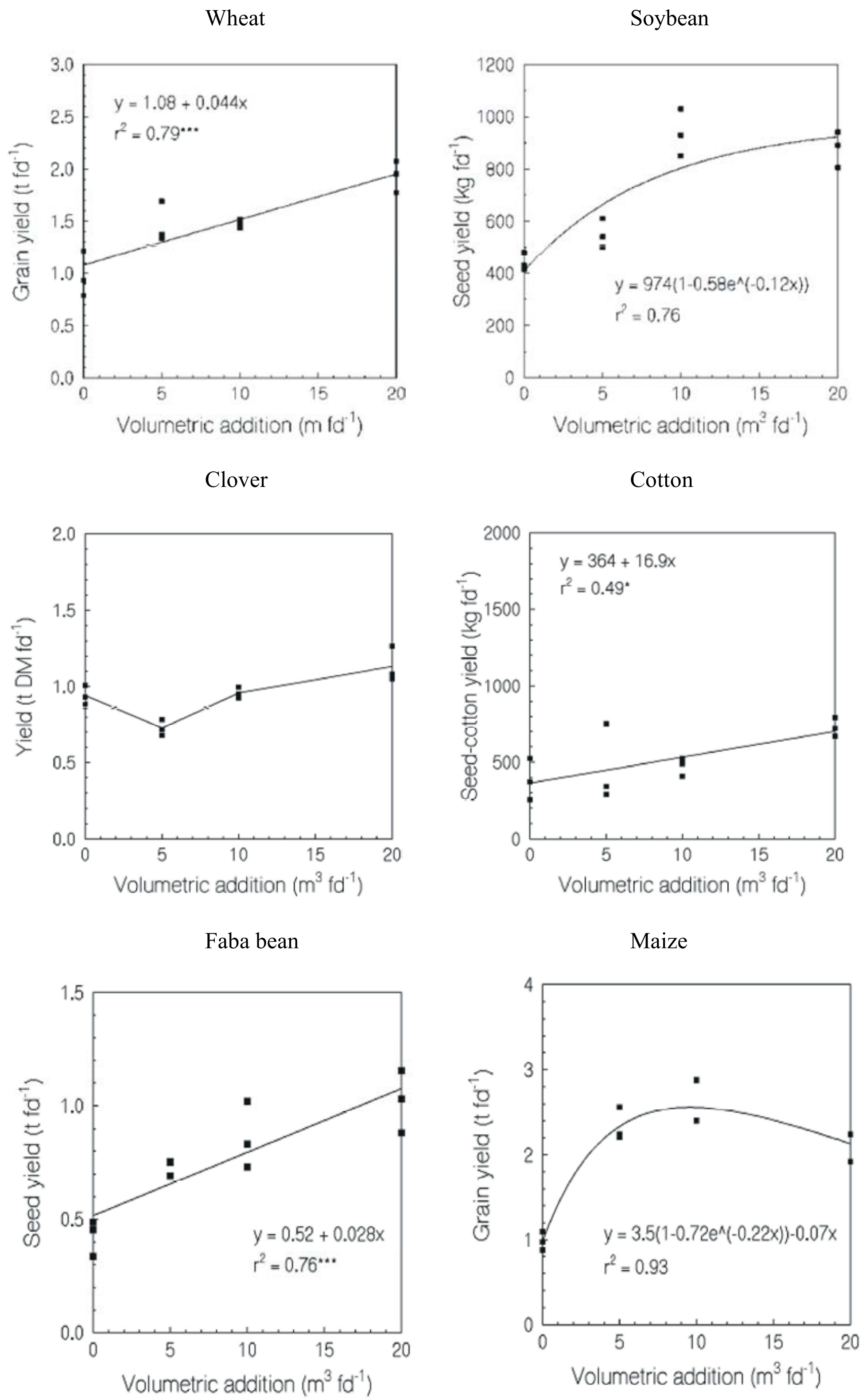

Fig. 4: Yield responses of different crops in a six season rotation in relation to volumetric additions of farmyard manure to clay soil (Nile alluvium)

elements and benefits to soil conditions from organic matter in the case of sludge. A large number of field trials on sludge reuse have been carried out by various studies, of which the Alexandria Effluent and Sludge Reuse Study and the Cairo Sludge Disposal Study are key examples from which scientifically-based practical guidance and extension have been derived CSDS [10-13].

N equivalency values were calculated for the sludge products and FYM on the basis of the total N additions to soil in the materials, relative to the yield profiles obtained with N fertilizer. The quantitative N equivalency values are listed in Table (2) and have confirmed the qualitative assessment of material performance determined by visual inspection of Figures 1, 2, 3 and 4.

The clearest picture of N availability for the different manures was obtained for the first crop of the rotation (wheat, winter season). This gave N equivalency for digested sludge of 50 %. The availability of N contained in raw sludge was about half that of the stabilised material. However, the results also show that the apparent N equivalency of raw and digested sludge increased as the trial progressed associated with the effects of cumulative additions of sludge on soil fertility and crop yields. The effectiveness of digested sludge as an N fertilizer is explained by the presence of residual amounts of inorganic ammonium-N from the digestion process. The N equivalencies estimated for FYM were less consistent than for sewage sludge, reflecting the more variable chemical composition of FYM and were usually similar to, or lower than, the sludge products. However, the N equivalency value calculated for FYM was apparently much larger than for sludge with soya bean. Farmyard manure increased seed yield of soya bean by 60 % compared with inorganic fertilizer supplied at equivalent rates of N addition. It could be concluded from this study that the N availability of raw sludge is 20 % of its total N content and digested sludge contains 50 % of available N for uptake by the first crop. This is equivalent to a N fertilizer replacement value of 40 kg N fd^{-1} at the recommended dressing of raw sludge (20 m^3 fd^{-1}) and 50 kg N fd^{-1} at the rate recommended for digested sludge (10 m^3 fd^{-1}) on clay soil. Similar results were confirmed by [14].

CONCLUSION

The N availability of raw sludge is 20 % of its total N content and digested sludge contains 50 % of available N for uptake by the first crop. This is equivalent to a N fertilizer replacement value of 40 kg N fd^{-1} at the recommended dressing of raw sludge (20 m^3 fd^{-1}) and 50 kg N fd^{-1} and was equal to application at the rate recommended for digested sludge (10 m^3 fd^{-1}) on clay soil

REFRENCES

1. Smith, S.R., 1996. Agricultural Recycling of Sewage Sludge and the Environment. CAB International, Wallingford, UK.
2. Gonzaga, M.I.S., C.L. Mackowiak, N.B. Comerford, E.F. da Veiga Moline, J.P. Shirley and D.V. Guimaraes, 2017. Pyrolysis methods impact biosolids-derived biochar composition, maize growth and nutrition. Soil and Tillage Research, 165: 59-65. https://doi.org/10.1016/j.still.2016.07.009
3. Tejada, M., B. Rodríguez-Morgado, I. Gómez, L. Franco-Andreu, C. Benítez and J. Parrado, 2016. Use of biofertilizers obtained from sewage sludges on maize yield. European Journal of Agronomy, 78: 13-19. https://doi.org/10.1016/j.eja.2016.04.014.
4. Singh, R.P. and M. Agrawal, 2008. Potential benefits and risks of land application of sewage sludge. Waste Management, 28: 347-358.
5. Sulewska, H. and W. Koziara, 2007. Effects of sludge application in maize growing. Zeszyty Problemowe Postêpów Nauk Rolniczych, 518: 175-183 (in Polish).
6. Szymañska, G., H. Sulewska and K. Śmiatacz, 2013. Response of maize grown for silage on the application of sewage sludge. Acta Scientiarum Polonorum, Agriculture, 12(3): 55-67.
7. Cooke, G.W., 1982. Fertilizing for Maximum Yield. Granada Publishing, 3rd ed London.
8. Cohort Software, Costate computer programme (Cohort 6.3.1 Software).
9. Colwell, J.K., 1994. Estimating fertilizer requirements: A quantitive approach .CAB International, Wallingford UK.
10. CSDS: Cairo Sludge Disposal Study, 1999a. Scientific Justification for Agricultural Use of Sewage Sludge in Egypt. Final Report, Phase 2. WRc report No. CSDR014. May 1999.
11. CSDS: Cairo Sludge Disposal Study, 1999b. Extension Guide for Agricultural Use of Sewage Sludge in Egypt. WRc report No. CSDR015. May 1999.
12. Mohamed, M.F., A.T. Thalooth, T.A. Elewa and A.G. Ahmed, 2019. Yield and nutrient status of wheat plants (*Triticum aestivum*) as affected by sludge, compost and biofertilizers under newly reclaimed soil. Bulletin of the National Research Centre, 43: 31-36.

13. Abd El Lateef, E.M., J.E. Hall, A.A. Farrag, M.S. Abd El-Salam and A.A. Yassin, 2019. The Egyptian experience in sewage sludge recycling in agriculture. Am-Euras. J. Agron., 12(2): 12-18.
14. Abd El Lateef, E.M., J.E. Hall, S.R. Smith, A.A. Farrag and M.M. Selim, 2007. Bio-Solid Recycling In Warm Climates: A Case Study: Cairo and Alexandria Sludge Reuse Studies. International Conference on sustainable Sanitation: Eco –Cities and Villages, 26-29 August 2007, Dong Sheng China, pp: 51.