Soil hydraulic and salinity restrictions to water availability in very sandy soils

Thesis submitted by

Justice Okona Frimpong

BSc. Hons. (General Agriculture), University of Cape Coast, Cape Coast, Ghana
Masters of Philosophy (Nuclear Agriculture), School of Nuclear and Allied Sciences, University of Ghana, Legon-Accra

For the degree of Masters of Philosophy

in the

School of Agriculture, Food and Wine
Faculty of Sciences
The University of Adelaide
Adelaide, South Australia, Australia

October, 2016
Table of content

Table of content.................................................................................................................. ii
Summary of thesis ................................................................................................................ iv
Declaration statement ........................................................................................................... vi
Acknowledgement ................................................................................................................ vii
Dedication ............................................................................................................................. ix

CHAPTER 1: General introduction ......................................................................................... 1

CHAPTER 2: Literature review ............................................................................................... 3

2.1 Plant available water ..................................................................................................... 3
2.2 Pore size distribution ................................................................................................... 4
2.3 Low soil aeration ......................................................................................................... 6
2.4 Low soil hydraulic conductivity .................................................................................. 7
2.5 High soil strength ....................................................................................................... 11
  2.5.1 Definition and measurement of soil strength ....................................................... 11
2.6 Osmotic stress caused by salt .................................................................................... 14
2.7 Recycled water: benefits and quality issues ............................................................... 16
2.8 Salinisation and sodification ....................................................................................... 17
2.9 Models to describe PAW ............................................................................................ 21
  2.9.1 PAW and Least Limiting Water Range ................................................................. 21
  2.9.2 Integral Water Capacity ..................................................................................... 26
2.10 Limitations to IWC model ......................................................................................... 29
2.11 Links to soil quality and plants .................................................................................. 29
2.12 Indicators of plant stress ............................................................................................ 32
  2.12.1 Measuring plant and soil water status ............................................................... 33
2.13 Summary and conclusions ......................................................................................... 38
2.14 Research questions .................................................................................................... 40
2.15 Hypotheses ................................................................................................................ 40
2.16 Proposed experiments ............................................................................................... 41

CHAPTER 3: Materials and methods to select soils .............................................................. 42

3.1 Introduction ................................................................................................................ 42
3.2 Selection of soil materials ............................................................................................ 42
3.3 Other physical characterisation of experimental materials ....................................... 44
  3.3.1 Particle density ........................................................................................................ 44
  3.3.2 Bulk density ........................................................................................................... 44
  3.3.3 Total porosity .......................................................................................................... 45
  3.3.4 Particle size distribution ....................................................................................... 45
  3.3.5 Saturated hydraulic conductivity, Ks .................................................................... 45
3.3.6 Water retention curves 0(h) ................................................................................. 47
3.4 Results and discussion ......................................................................................... 48
3.5 Conclusion ............................................................................................................. 50

CHAPTER 4: Inflection points on water retention curves ........................................... 51
4.1 Introduction ........................................................................................................... 51
4.2 Preliminary evaluation of water retention data ......................................................... 51
4.3 Curve fitting of the water retention data ................................................................. 52
4.4 Matric suctions either side of the inflection point in the water retention curves .... 53
4.5 Results and discussion ......................................................................................... 55
4.6 Conclusions .......................................................................................................... 60

CHAPTER 5: Wheat response to soil moisture conditions at and surrounding the point
of inflection in the soil water retention curve for coarse textured soils ................. 61
5.1 Introduction ........................................................................................................... 61
5.2 Materials and Methods ......................................................................................... 62
  5.2.1 Experimental materials .................................................................................... 62
  5.2.2 Experimental factors and design ..................................................................... 62
  5.2.3 Soil water contents .......................................................................................... 63
  5.2.4 Wheat establishment in pots .......................................................................... 65
  5.2.5 Conditions in glasshouse ................................................................................ 65
    5.2.5.1 Seeding and nutrient application ................................................................. 66
    5.2.5.2 Daily watering regime ............................................................................ 67
  5.2.6 Harvest measurements ................................................................................... 68
  5.2.7 Statistical analysis .......................................................................................... 68
5.3 Results and discussion .......................................................................................... 68
  5.3.1 Soil water contents and matric heads during growing period ......................... 68
  5.3.2 Shoot and Root responses .............................................................................. 70
5.4 Conclusions .......................................................................................................... 75

CHAPTER 6: Summary, conclusions and suggestions for future research ............... 76

CITED REFERENCES .................................................................................................. 79

APPENDIX ............................................................................................................... 95
  Appendix 1 ............................................................................................................. 95
  Appendix 2 ........................................................................................................... 101
  Appendix 3 ........................................................................................................... 103
Summary of thesis

This study tried to evaluate the veracity of Grant and Groenevelt (2015) assertion that the inflection point on the water retention curve (WRC), plotted on semi-log scale, marks the onset of hydraulic stress in plants grown in sandy soils. That is, as the soil dries during drainage and evapotranspiration, there comes a point (argued to be the inflection point) when the unsaturated hydraulic conductivity cannot keep up with plant demand for water; thus, plants begin to suffer. Interest in the inflection point stemmed from the need to find unbiased criteria to weight the water capacity downward in the integral water capacity (IWC) model of Groenevelt et al. (2001) to account for soil hydraulic restrictions. If the inflection point was truly a good indicator of the onset of plant stress, then the matric suction at this point can easily be found from the fitting parameter, $k_0$ (m), in Grant and Groenevelt (2015) water retention model; by coincidence it can also be found from the fitting parameter, $1/\alpha$ (m) in the water retention model of (Van Genuchten 1980).

The experimental components of this study consisted of two main parts: In the first part, water retention curves for a range of different sands and sandy soils were prepared, their inflection points identified, and two points on either side of the inflection point (wetter and drier) identified (Chapters 3 and 4). In the second part, wheat plants were grown in a glasshouse to Zadoks et al. (1974) growth stage 21 in pots of the different sands held, constant, at three different soil water suctions: at, above and below the inflection point (Chapter 5).

Detailed water retention curves were prepared using multiple replicates (up to 20) of four sands and two sandy soils (Very coarse sand, Coarse sand, Medium sand, Fine sand, Very fine sand, and Sandy loam) placed in small rings on ceramic pressure plates at different matric suctions ranging from saturation to 25 kPa or greater. Each of the individual sets of water retention data (up to 20) were fitted to the water retention models of Groenevelt and Grant (GG), and Van Genuchten (VG), and the inflection points identified from the appropriate fitting parameters. As might be expected, the different models produced slightly different inflection points, but these indeed corresponded pretty well (but not precisely) with $k_0$ and $1/\alpha$ respectively. There was a strong inverse correlation between the mean particle size of the sands and sandy soils, and the values of $k_0$ and $1/\alpha$; that is, the inflections points shifted to greater matric suctions as mean particle size decreased, such that the Very coarse sand had the smallest values of $k_0$ and $1/\alpha$ while the Sandy loam had the largest values of $k_0$ and $1/\alpha$.

Because the VG model fitted the measured water retention data slightly better than did the GG model, the parameters from the VG model were chosen to identify the soil water conditions for
the plant experiments. The matric suction at the inflection point, \( h_i \) (m), was identified from \( 1/\alpha \), and this corresponded with the maximum differential water capacity, \( C(h_i) \). The wetter, \( h_w \), and drier, \( h_d \), matric suctions were chosen to correspond with the matric suctions at 90 % of the maximum differential water capacity (on either side of the inflection point). The value 90 % was chosen as being close to the inflection point yet falling outside its 95 % confidence interval. The (up to) 20 estimates of \( h_w \), \( h_i \) and \( h_d \) were used to identify the corresponding volumetric water contents directly from the water retention curves, and these were averaged and converted to gravimetric water contents that could be used to set up the soil water conditions in the pot study.

Following a 6 x 2 x 3 completely randomised factorial design, litre-sized pots of each sand or sandy soil (5 replicates) were set up at the three different water contents corresponding to \( h_w \), \( h_i \) and \( h_d \), (covered in plastic beads to minimise evaporation) and wheat seeds (2 different genotypes) planted and grown in them to growth stage 21. To keep soil water contents constant, daily pot weights were recorded and then water added (calibrated for increasing plant mass over time) to replace water evapo-transpired. The measure of plant response to the soil water conditions was the mass (fresh and dry) of shoots and roots.

Although one of the wheat genotypes performed significantly better than the other (consistent with the literature), the F-test or analysis of variance (ANOVA) indicated that the wheat genotypes never responded to the soil moisture conditions or matric suction effects at or surrounding the inflection point. Possible reasons for the lack of response to the soil moisture conditions may be related to the choice of the wet and dry-side matric heads, particularly on the dry side; that is, the matric suction on the dry side of the inflection point, which corresponded to 90 % of the maximum water capacity, may not be sufficiently dry to induce a hydraulic stress. Contrast to this, was the source of variation that arose from the three and two factor interaction effects on the dry weights of shoot and root respectively, which showed significant differences. However, this was not convincing enough for one to accept the null hypothesis of the study due to the inconsistent nature of trends observed in the dry weights obtained at or surrounding the inflection point matric suction. On this basis, the importance of the inflection point as a marker of hydraulic stress in plants is not rejected at this stage – further research is needed.
Declaration statement

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I also give permission for the digital version of my thesis to be made available on the web, via the University’s digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for some time.

__________________________________________  ________________________________________
Date                                               Justice Okona Frimpong
Acknowledgement

To begin with, I was highly honoured when I won the Adelaide Scholarship International (ASI) from Ghana to come and pursue postgraduate studies at the University of Adelaide. Thanks to the ASI, who funded my tuition fee and living allowance. I also duly acknowledge the support from the Australian Research Council (ARC) of Centre of Excellence (CoE), recycled water quality grant used for supporting my research work.

My sincere gratitude goes to the Ghana Atomic Energy Commission (GAEC), who granted me study leave with pay to come to the University of Adelaide, for this advance study in field of applied soil physics to crop water use. This extends to the administrative and management staff of the Biotechnology and Nuclear Agriculture Research Institute (BNARI), who also facilitated the study leave offer, especially my co-workers at both the Nuclear Agriculture Centre (NAC) and the Soils and Environmental Science Centre (SESC).

I express deep gratitude and sense of obligation to my principal supervisor Dr. Cameron D. Grant for his inspiring attitude, consoling behaviour and encouragement throughout the conduct of my research project and preparation of this thesis. Furthermore, this sincere gratitude extends to my co-supervisors in the persons of Associate Prof. Timothy Cavagnaro and Prof. Jim W. Cox, who also contributed immensely to the preparation of this thesis through their constructive criticism on the various drafts that I submitted for comments.

I am also thankful to my postgraduate coordinator, Prof. Eileen Scott, who chaired meetings, held for the various milestones assigned to the programme of study. This extends to my independent advisor and senior academic person, Dr. Robert Murray and Dr. Ronald Smernik, respectively for going through some of the initial drafts that I turn in for comments. In addition, I thank them for their support during my core component structure programme (CCSP) and major review (MR) seminar.

I humbly acknowledge the support I received from Mr. Tim Pitt of the Southern Australian Research and Development Institute (SARDI), for the trip to the Almond Orchard recycled water irrigation field to collect soil samples for my experiment. Not forgetting the Almond Orchard field owner, Mr. Nick, who allowed us on his property to collect soil sample. Also, to Dr. Gilliham Matthew of the University of Adelaide, for giving me wheat seeds.

Thanks to Ms Rebecca Stonor and Mr. Ahsan Chowdhury for the induction, they both gave me in glasshouse and laboratory respectively, which enhanced the completion of my experimental works. A similar acknowledgement is also extended to Mr. Colin Rivers, who supported me in field laboratory.
My appreciation goes to the entire soil science group of the School Agriculture, Food and Wine, under the faculty of science in the University of Adelaide, who supported me during the series of seminars that I gave within my candidature before completion of this programme. I extend same to colleague PhD and Master Candidates in the soil science group as well, who also gave me the necessary audience during my seminar presentations.

Finally, to the Waite security staff who provided security after hours during my experimental activities.
Dedication

I dedicate this thesis to my immediate extended family: siblings, mother (Gladys Ekua Otomo, a widow), little nephews and nieces, who supported me with prayers and guidance.

This is also dedicated to my distance relatives, Dr. Joseph Kwasi Ayim Boakye and Mr. William Atta Yeboah, formerly of the University of Cape Coast and Ghana Atomic Energy Commission respectively, church group members (Church of Pentecost, Hebron Assembly, Accra, Ghana) and everyone who wished me well from the time I begun this two years’ academic journey.

Last but not the least to my late father (Mr. Seth Kwabena Effah), who supported me with his hard, earned money during my days at the University of Cape Coast and Presbyterian Boys’ Senior High Secondary School, Legon, Accra. Thanks, very much father may your soul rest in perfect peace.