

**Universidade de São Paulo
Escola Superior de Agricultura “Luiz de Queiroz”**

Avanços metodológicos e instrumentais em física do solo

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Tese apresentada para obtenção do título de Doutor em Ciências. Área de concentração: Solos e Nutrição de Plantas

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1 RESUMO

Os ecossistemas naturais e agropecuários dependem fundamentalmente do solo como recurso básico para sua funcionalidade. Neste contexto, a qualidade do solo tem tido uma crescente importância global. Os objetivos deste estudo consistiram em propor modificações metodológicas e/ou instrumentais visando determinações mais acuradas dos indicadores da qualidade física do solo mediante o desenvolvimento de (i) um sistema eletro-mecânico que permite a obtenção de amostras indeformadas de solos sem aplicação de golpes; (ii) um penetrômetro estático automatizado, de baixo custo e portátil, para medidas de resistência à penetração (RP) e resistência tênsil (RT) sob regime de velocidade constante de $1,55 \text{ mm s}^{-1}$; (iii) um consolidômetro, de baixo custo e de maior portabilidade, para determinações da curva de compressão do solo, da RP e da RT utilizando propulsão pneumática e (iv) melhorias instrumentais em um permeâmetro de carga constante de ar pela redução de oscilações durante a medição do gradiente de pressão bem como a otimização da seleção de diferentes níveis de vazão mássica de ar. Os resultados obtidos mostraram que (i) o sistema eletro-mecânico garantiu a preservação da estrutura do solo em amostras coletadas comparado com a amostragem por golpes, principalmente no solo mais argiloso; (ii) a RP e a RT puderam ser determinadas com elevada acurácia à velocidade constante de $1,55 \text{ mm s}^{-1}$; (iii) a curva de compressão do solo foi sensível às diferenças entre os tratamentos (linha e entrelinha da cultura) e a utilização de propulsão pneumática não influenciou os resultados da RP e da RT e (iv) a instrumentação utilizada no permeâmetro de carga constante de ar permitiu realizar determinações da permeabilidade do solo ao ar tanto em campo quanto em laboratório com rapidez e elevada acurácia.

2 INTRODUÇÃO

A compactação é um dos processos que mais afeta a estrutura do solo. Este processo ocorre em um sistema tridimensional, induzido por estresses mecânicos comumente originados do tráfego de máquinas e da ação de implementos agrícolas e/ou do pisoteio de animais, podendo ocasionar deterioração da qualidade física do solo e limitar o potencial de produção agrícola. Os indicadores da qualidade do solo são ferramentas recorrentes para a avaliação da sustentabilidade do uso da terra e das práticas de manejo. Para tanto, várias propriedades têm sido utilizadas para quantificar e descrever as alterações ocorridas nos processos físicos, químicos e biológicos do ecossistema em função de sua exploração agrícola. Muitos dos estudos relacionados à Física, Conservação e Manejo do Solo têm obtido resultados pouco conclusivos ou contraditórios, em parte, devido à utilização de metodologias ineficientes para avaliar a qualidade do solo. Frequentemente, tais metodologias envolvem determinações de propriedades físicas em amostras indeformadas, que são submetidas a diferentes ensaios laboratoriais visando a quantificação de indicadores da qualidade do solo. Neste contexto, pode-se elaborar como hipótese que a melhoria da amostragem de solos bem como das técnicas laboratoriais relacionadas à determinação das propriedades físicas em amostras indeformadas permite obter resultados mais confiáveis sobre o estado da qualidade estrutural do solo.

Dessa forma, o objetivo geral deste estudo foi propor modificações metodológicas e/ou instrumentais relacionadas à Física do Solo visando determinações mais acuradas de indicadores da qualidade do solo bem como uma maior inclusão de algumas propriedades físicas em rotinas laboratoriais.

Os objetivos específicos, que corresponderam aos diferentes capítulos, foram:

- a) Desenvolver um sistema eletro-mecânico que permite a extração de amostras de solos sem aplicação de golpes e avaliá-lo a partir da determinação de algumas propriedades físicas indicadoras da qualidade do solo;
- b) Desenvolver um penetrômetro estático automatizado, de baixo custo e portátil, e avaliá-lo a partir de determinações de resistência à penetração (RP) em laboratório; ajustar os dados de RP, obtidos com velocidade constante de $1,55 \text{ mm s}^{-1}$, por meio de equações não-lineares em função do teor de água e da densidade do solo e verificar a similaridade dos coeficientes ajustados com aqueles obtidos em outros trabalhos;

avaliar a viabilidade deste equipamento em medir a resistência tênsil de agregados (RT) utilizando uma velocidade constante de compressão igual a $1,55 \text{ mm s}^{-1}$ em relação àquela de $0,03 \text{ mm s}^{-1}$ (referência);

c) Desenvolver e avaliar a funcionalidade de um consolidômetro pneumático, de baixo custo, para determinações da curva de compressão do solo; avaliar o potencial de utilização da propulsão pneumática em determinações de RP e de RT;

d) Construir um permeâmetro de carga constante de ar com alta portabilidade e útil para determinações da permeabilidade do solo ao ar, tanto no campo quanto em laboratório, a partir da implementação de instrumentos dedicados à redução de oscilações durante as medições do gradiente de pressão bem como a otimização da seleção de diferentes níveis de vazão mássica de ar, visando tornar mais simples a sua operação.

3 CONCLUSÕES

3.1 Capítulo 3

1 - A metodologia proposta para a obtenção de amostras indeformadas de solo com o amostrador elétrico foi apropriada;

2 - A eficiência do amostrador elétrico foi comprovada pelas menores alterações na estrutura das amostras coletadas e pelo seu tamanho reduzido, que permite amostragens de solo com e sem culturas e cujo peso do conjunto (estrutura mecânica, motor, bateria elétrica etc.) não prejudica a locomoção e utilização do equipamento;

3 - Ambos os amostradores foram sensíveis na caracterização da estrutura de solo entre as camadas avaliadas. Porém, apresentaram magnitudes distintas entre si em função da classe textural do solo;

4 - A variabilidade espacial das propriedades físicas do solo dependeu do modo de introdução dos anéis volumétricos;

5 - A introdução do anel volumétrico com velocidade de 2 mm s^{-1} foi mais adequada à preservação das propriedades físicas do solo;

6 - Para estudos mais detalhados sobre geometria do espaço poroso e transmissibilidade de fluidos no solo, recomenda-se a utilização do amostrador elétrico.

3.2 Capítulo 4

1 - O equipamento proposto foi adequado às determinações de resistência do solo à penetração em laboratório, cujo ajuste dos dados mediante regressão não-linear permitiu diferenciar os tratamentos de forma satisfatória, apresentando coeficientes similares àqueles de outros trabalhos;

2 - Não houve diferença significativa da resistência tênsil determinada sob velocidades constantes de compressão dos agregados com magnitudes de $0,03$ e $1,55 \text{ mm s}^{-1}$;

3 - As resistências à penetração e a tênsil de solos podem ser determinadas com elevada acurácia utilizando unicamente o equipamento proposto.

3.3 Capítulo 5

1 - O consolidômetro pneumático desenvolvido neste trabalho obteve desempenho satisfatório nos ensaios de compressão uniaxial e permitiu estimar a curva de compactação, o índice de compressão e a pressão de preconsolidação em amostras indeformadas de solo, possibilitando detectar com elevada acurácia os diferentes graus de consolidação bem como as distintas histórias de tensão da estrutura do solo em função da posição de amostragem;

2 - A resistência do solo à penetração e a resistência tênsil de agregados apresentaram valores coerentes com as recomendações da literatura, sendo possível determinar essas propriedades físicas utilizando unicamente o consolidômetro proposto;

3 - O custo relativamente mais baixo do consolidômetro proposto é um atrativo ao desenvolvimento de estudos mais detalhados sobre o potencial de utilização da propulsão pneumática nas determinações de resistência do solo à penetração e de resistência tênsil de agregados.

3.4 Capítulo 6

1 - O permeâmetro proposto foi adequado para determinações da permeabilidade do solo ao ar tanto no campo quanto em laboratório, além de ser altamente portátil;

2 - Os diferentes graus de compactação do solo entre as posições de amostragem foram sensivelmente detectados pelas propriedades físicas medidas, em especial pela permeabilidade do solo ao ar. O permeâmetro proposto pode ser utilizado para avaliar com rapidez e elevada acurácia as diferenças ou mudanças na funcionalidade do sistema poroso do solo;

3 - A operação do conjunto instrumental do permeâmetro proposto foi fácil e simples, sendo necessário realizar poucos ajustes para seu funcionamento.

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