Predicting moisture content and bulk density of various grains from their dielectric properties

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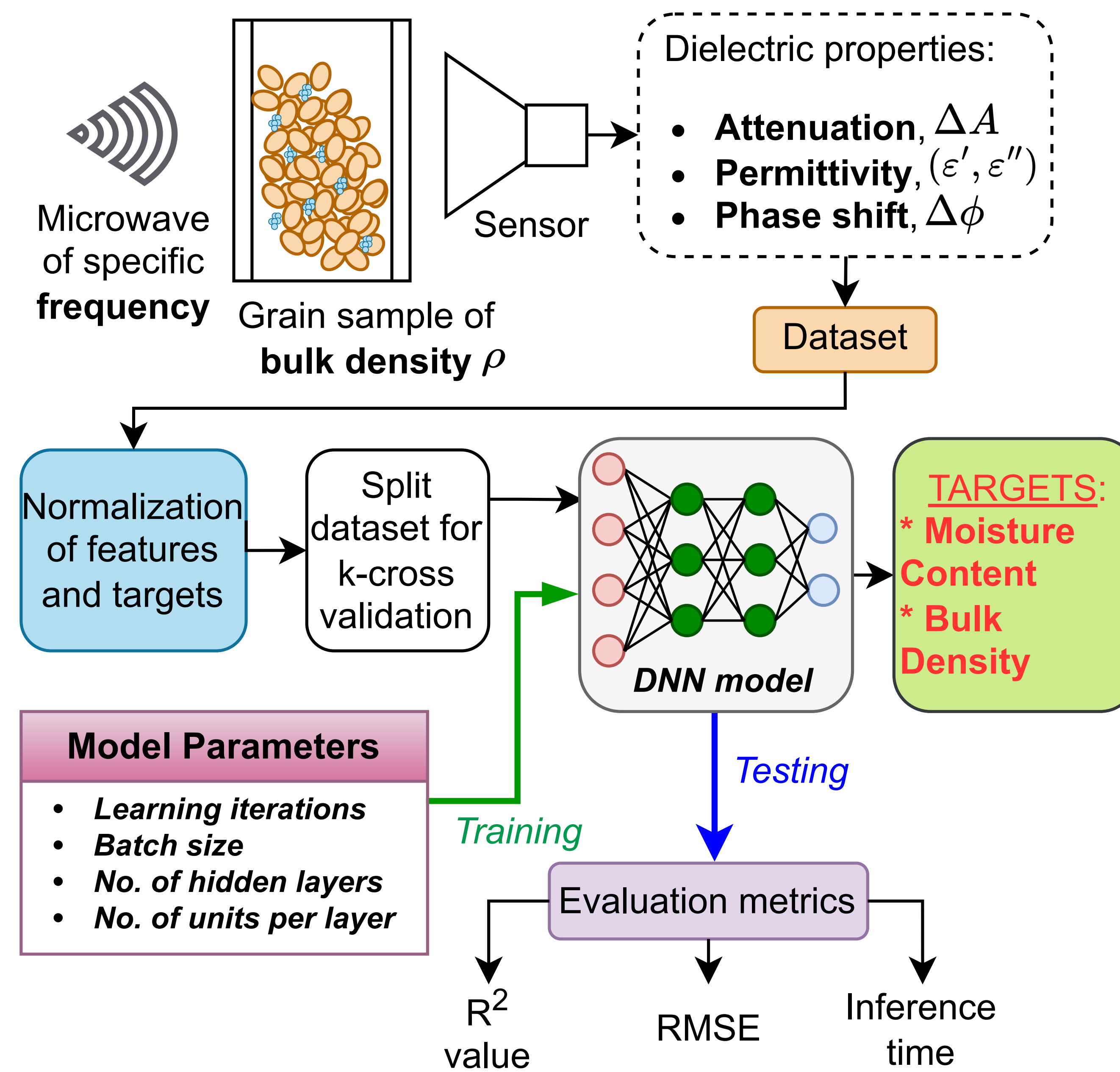
Background and Motivation

- Moisture content of grains is a critical variable in the buy-sell process to monitor quality production and crop analysis.
- Water's polar nature leads to correlate microwave frequencies and dielectric properties of moisture-containing materials.
- These properties can contribute to calculate moisture content of grains using calibration equations and non-destructive 'free-space' transmission techniques.
- Nevertheless, there are errors associated with calibration-based methods which can be further reduced.
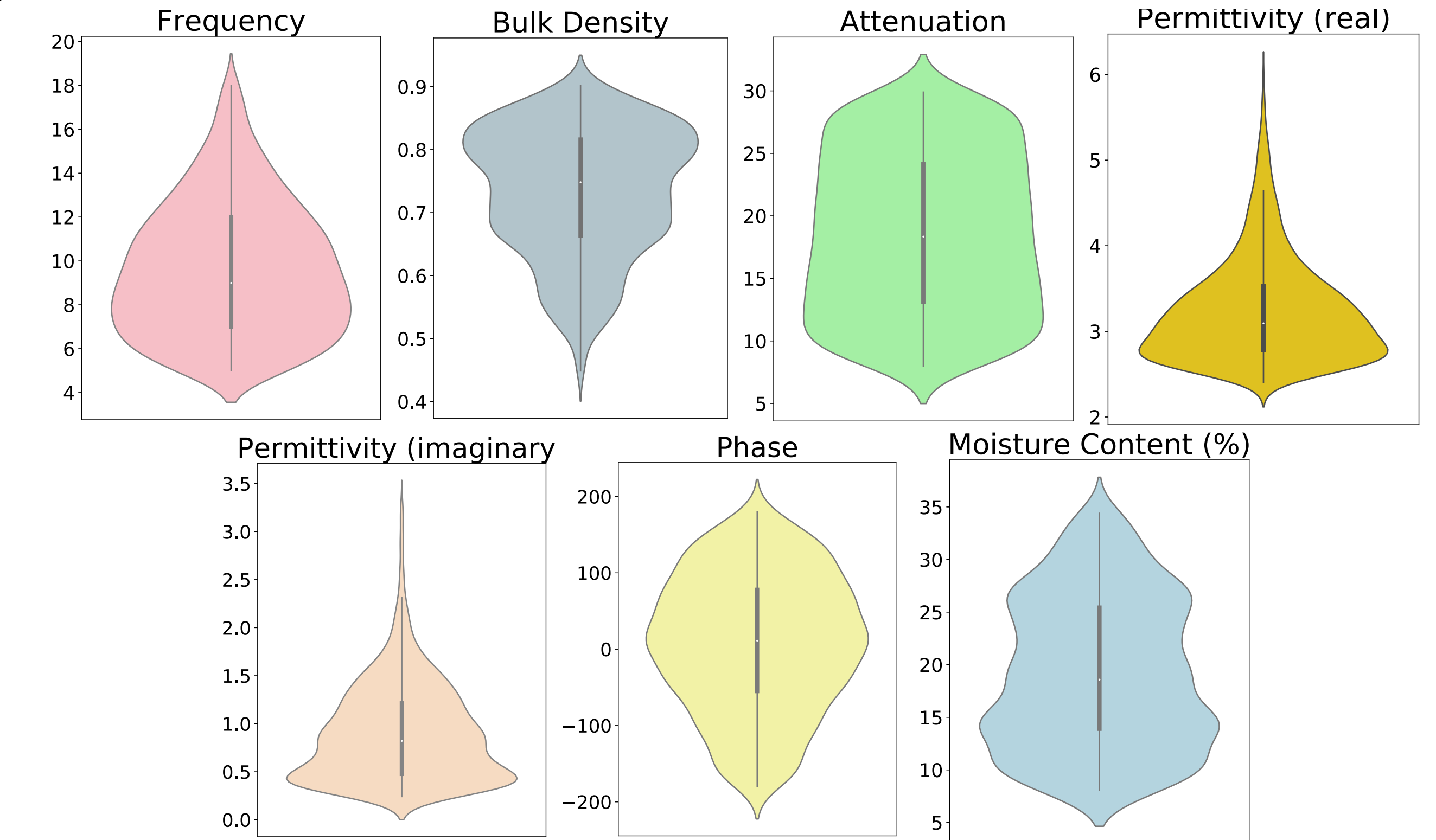
Objectives

- Provided a dataset of different microwave <u>frequencies</u> and corresponding <u>dielectric properties</u> measurements, we predict **Moisture Content** and **Bulk density** of different grains.
- Features of the dataset include:
  - *Microwave frequency*
  - *Permittivity*
  - *Attenuation*
  - *Phase shift*
- Grains considered in this study are as follows (dataset size in parentheses):
  - Wheat (806)
  - Sorghum (399)
  - Barley (366)
  - Soybeans (571)
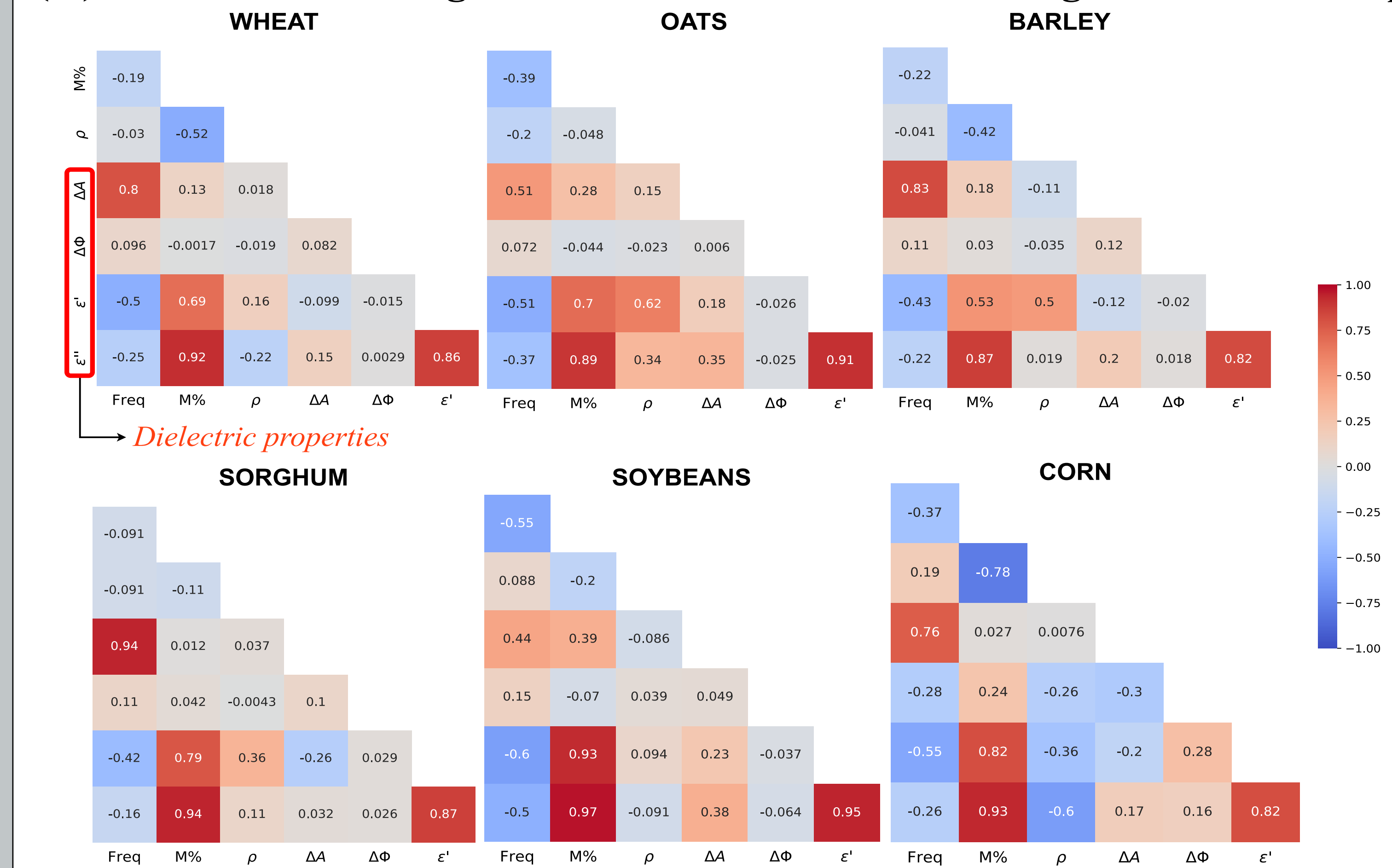 - Oats (485)
  - Corn (1339)

Methodology

Microwave of specific **frequency** → Grain sample of **bulk density** ρ → Sensor → Dielectric properties:
- **Attenuation**, ΔA
- **Permittivity**, $(\varepsilon', \varepsilon'')$
- **Phase shift**, $\Delta \phi$

→ Dataset → Normalization of features and targets → Split dataset for k-cross validation → DNN model → TARGETS: * Moisture Content * Bulk Density

Model Parameters
- *Learning iterations*
- *Batch size*
- *No. of hidden layers*
- *No. of units per layer*

Training → Testing → Evaluation metrics → R^2 value | RMSE | Inference time

Visualizing the dataset

(I) Distribution of dataset features in Violin Plots for Corn

Frequency | Bulk Density | Attenuation | Permittivity (real) | Permittivity (imaginary) | Phase | Moisture Content (%)

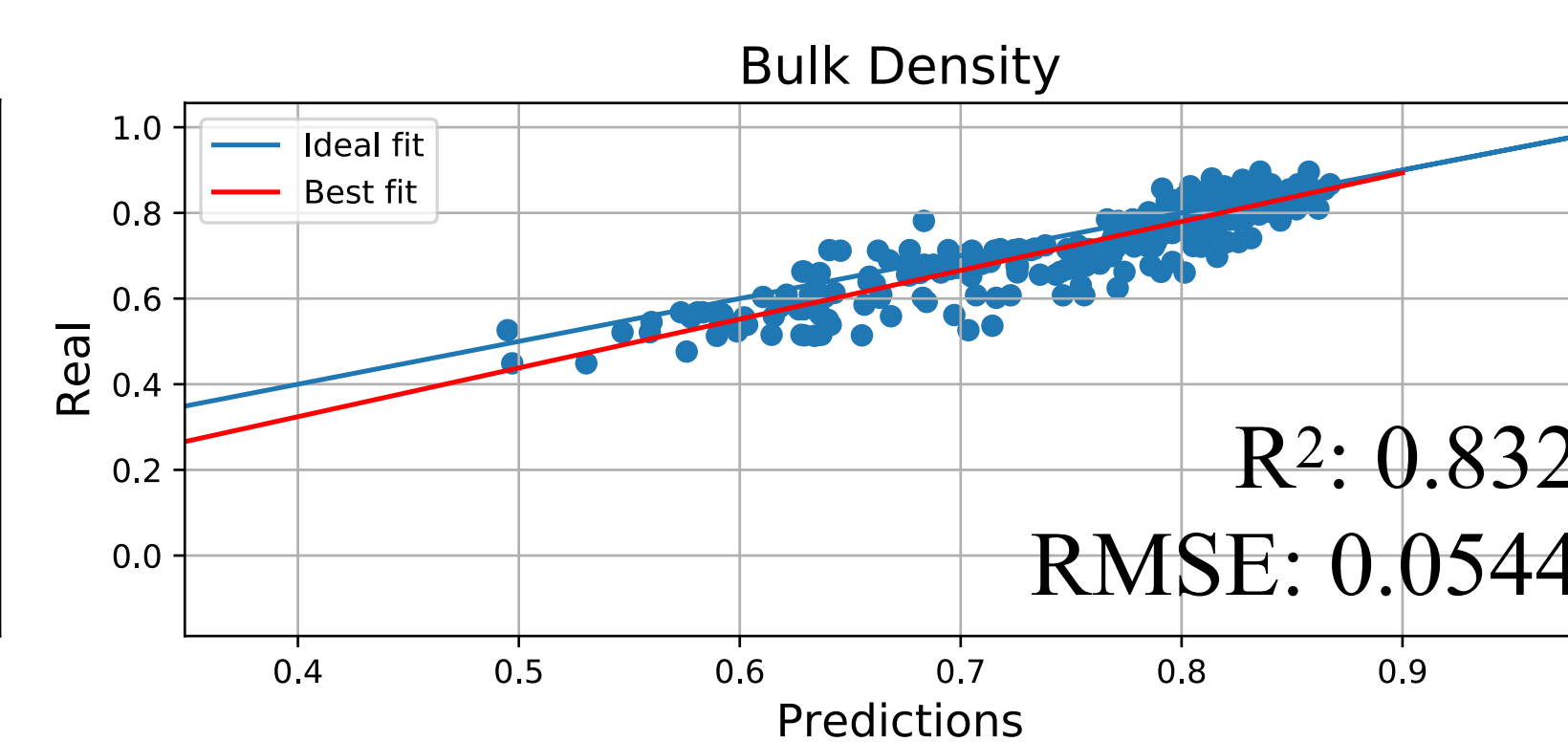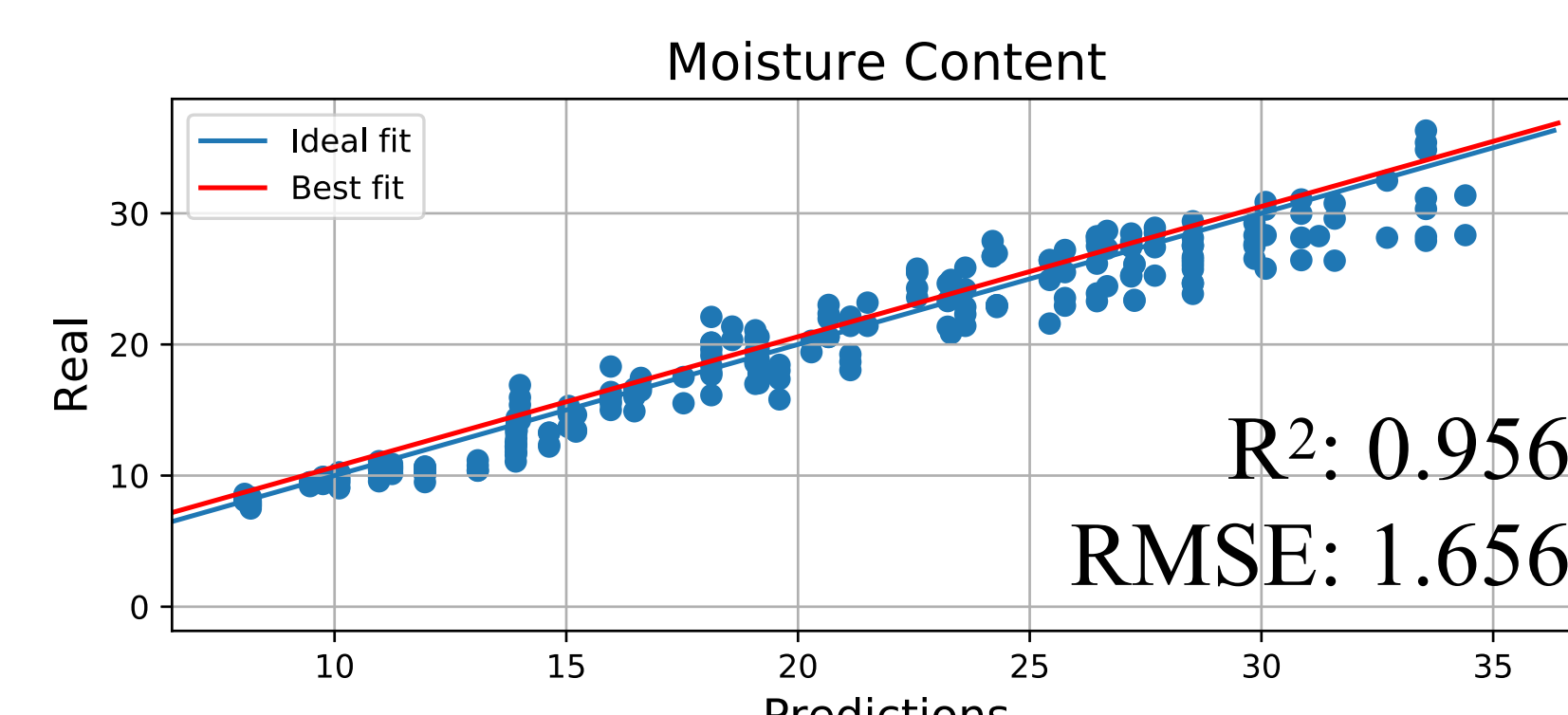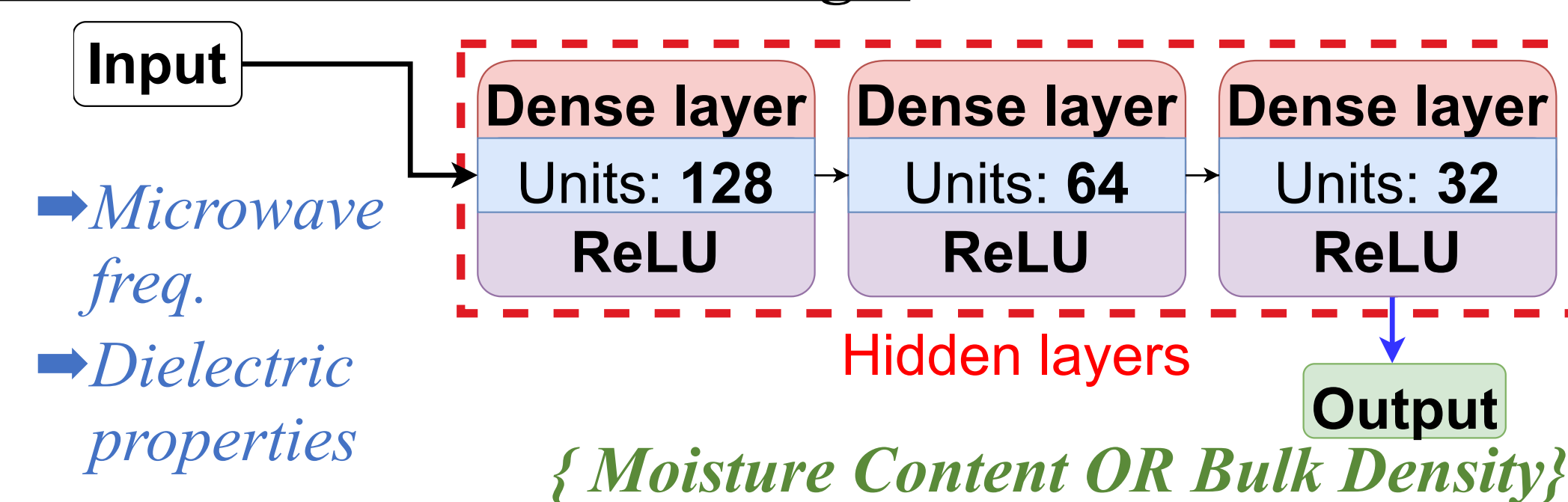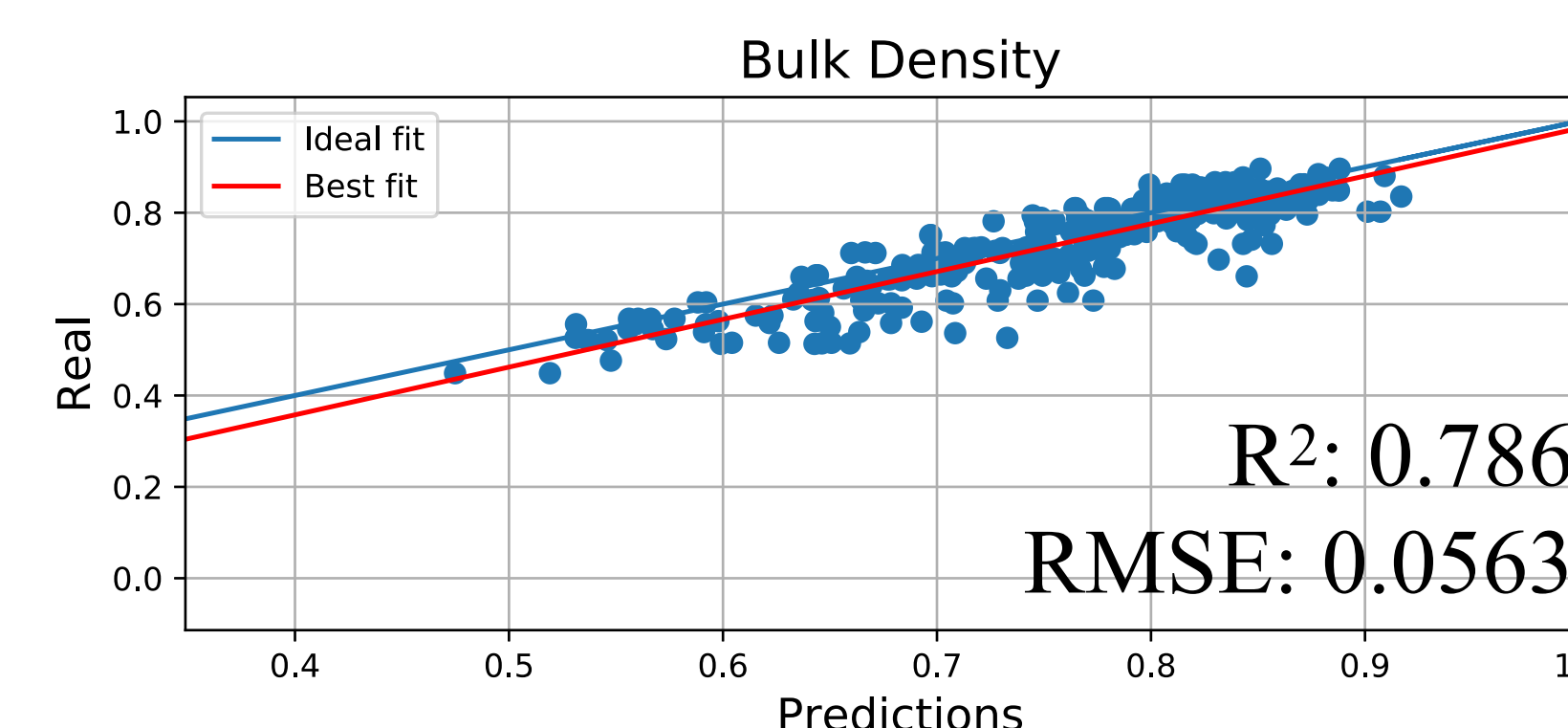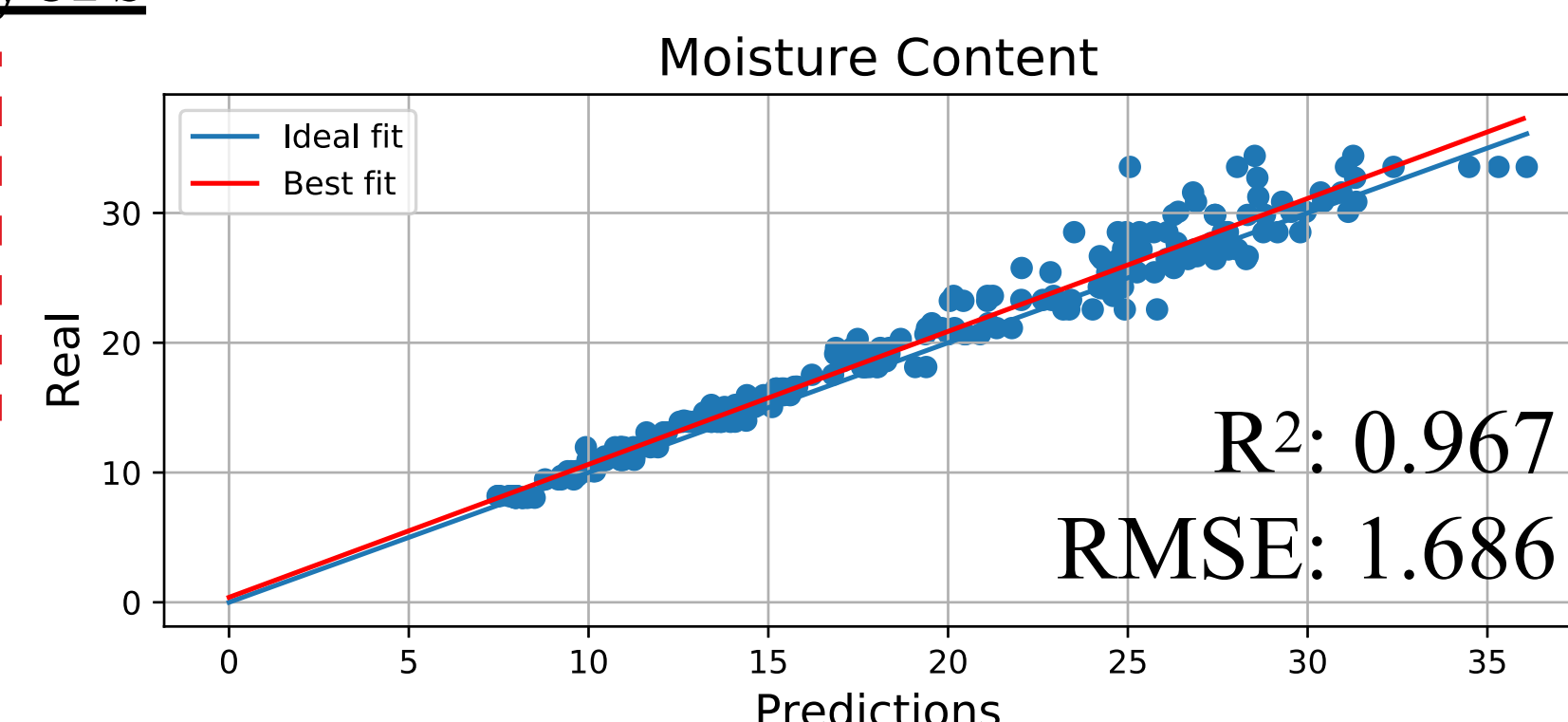**(II) Correlation amongst dataset features for different grains in Heatmap**

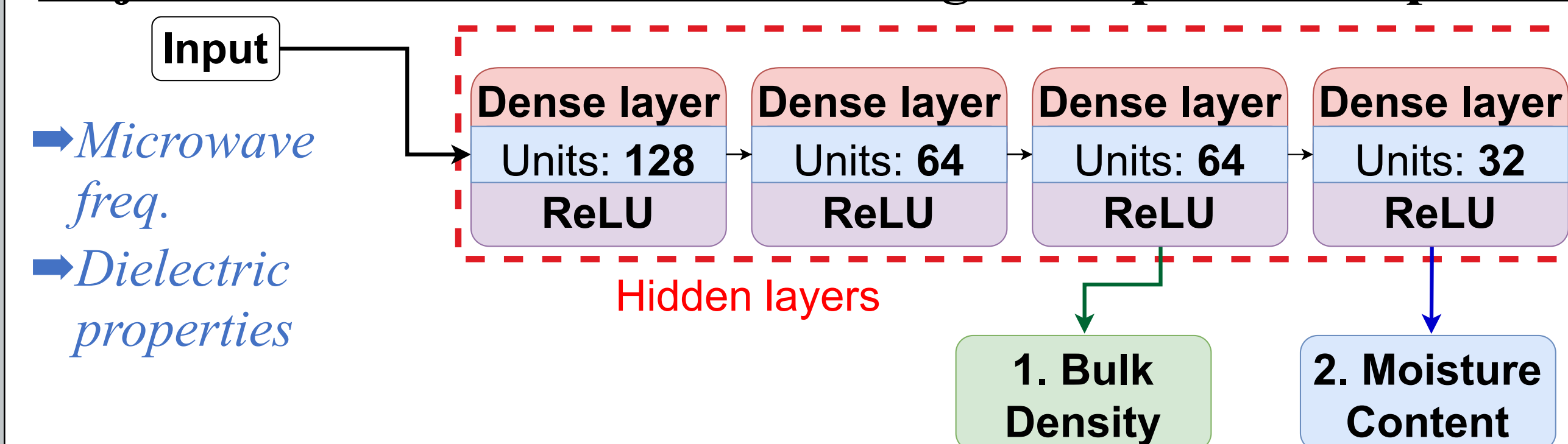WHEAT | OATS | BARLEY | SORGHUM | SOYBEANS | CORN

Model architecture and variants explored

Objective I: Prediction of ONE target

Input → Dense layer Units: **128** ReLU → Dense layer Units: **64** ReLU → Dense layer Units: **32** ReLU (Hidden layers) → Output { Moisture Content OR Bulk Density}

➡ *Microwave freq.*
➡ *Dielectric properties*

Moisture Content — R²: 0.956, RMSE: 1.656
Bulk Density — R²: 0.832, RMSE: 0.0544

Objective II: Prediction of TWO targets: Separate Output Layers

Input → Dense layer Units: **128** ReLU → Dense layer Units: **64** ReLU → Dense layer Units: **64** ReLU → Dense layer Units: **32** ReLU (Hidden layers) → 1. Bulk Density / 2. Moisture Content

➡ *Microwave freq.*
➡ *Dielectric properties*

Moisture Content — R²: 0.967, RMSE: 1.686
Bulk Density — R²: 0.786, RMSE: 0.0563

Objective III: Prediction of TWO targets: Single Output Layer

Input → Dense layer Units: **64** ReLU → Dense layer Units: **64** ReLU → Dense layer Units: **64** ReLU (Hidden layers) → Output { Moisture Content, Bulk Density}

➡ *Microwave freq.*
➡ *Dielectric properties*

Moisture Content — R²: 0.969, RMSE: 1.513
Bulk Density — R²: 0.808, RMSE: 0.0518
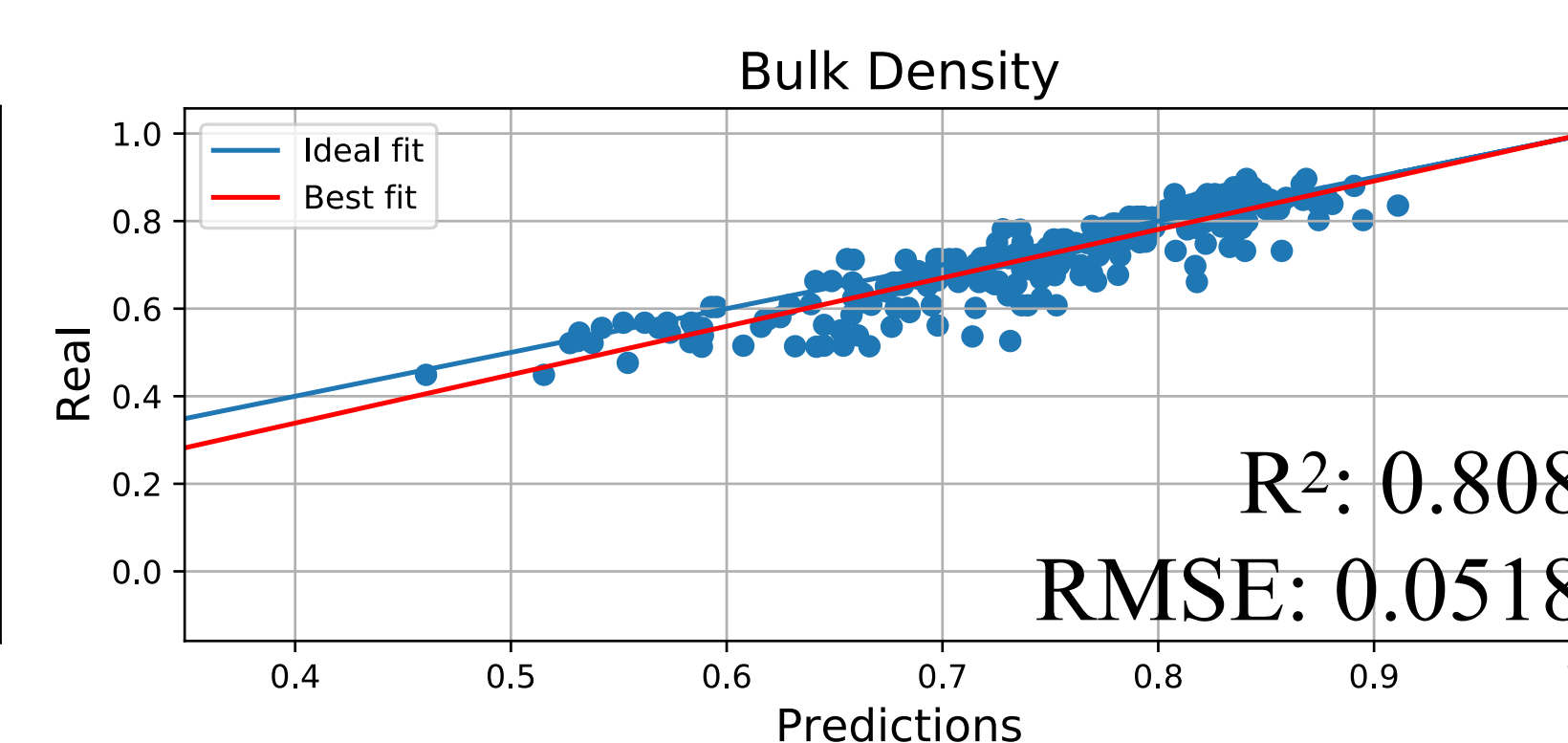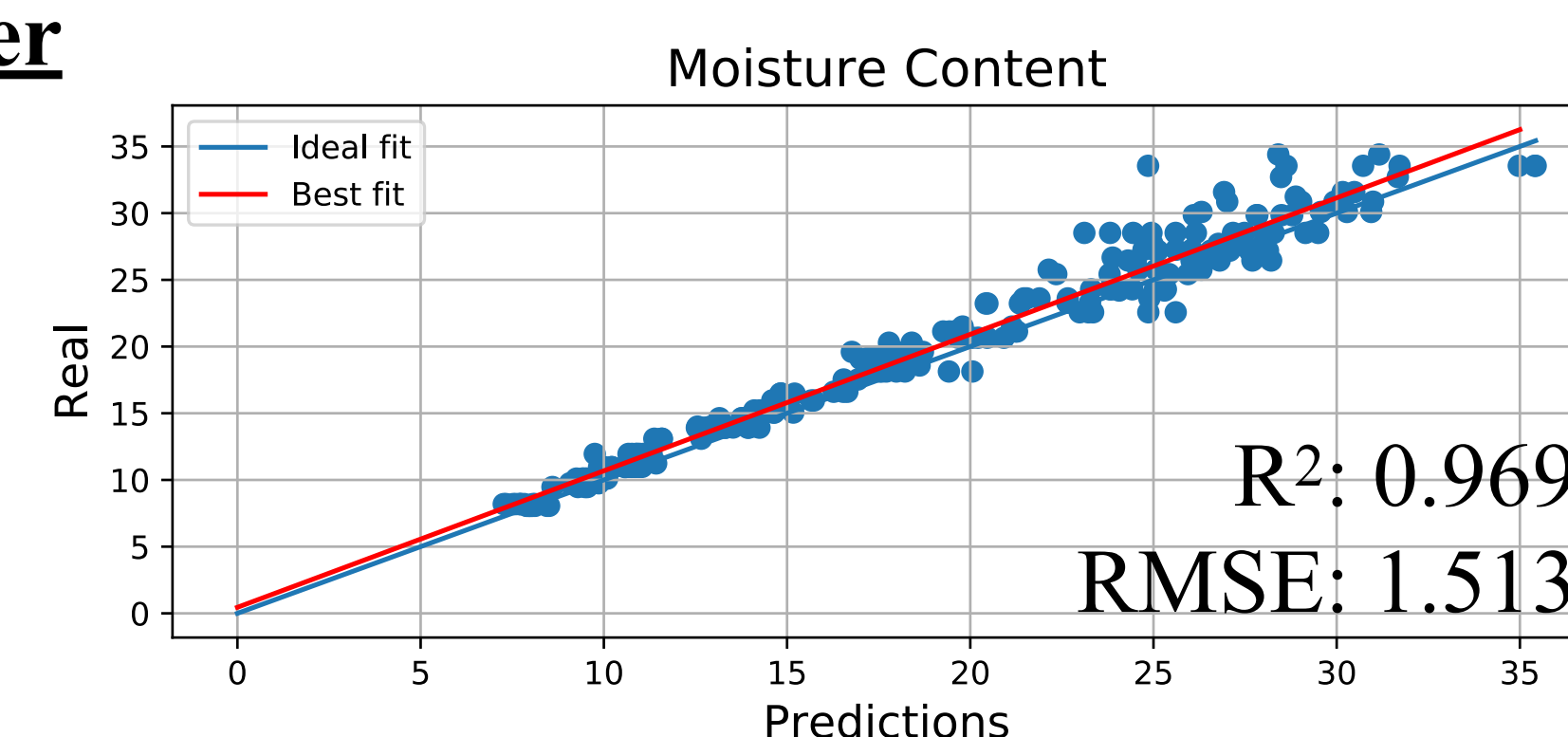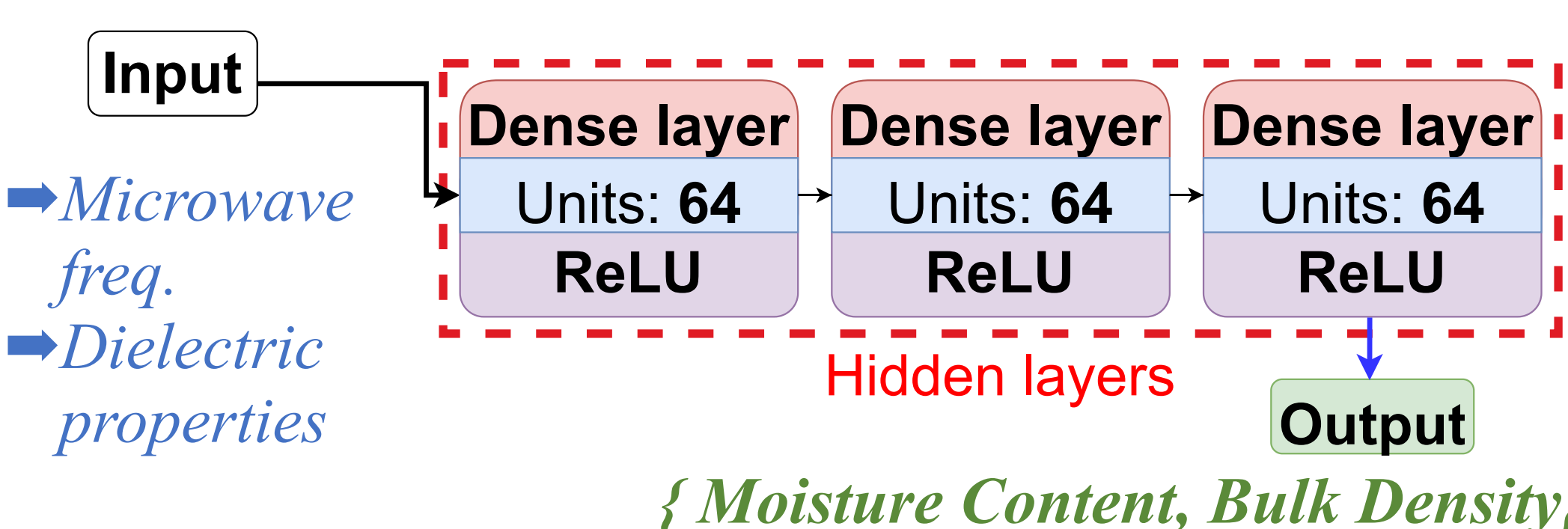
Results and Future Work

Metrics used	Moisture content	Bulk density
R² values	0.95 to 0.991	0.835 to 0.958
RMSE	0.739 to 1.875	0.0192 to 0.0693
Inference time	24ms to 59ms	

- OATS performed best in terms of both outputs
- SORGHUM performed worst for both outputs
- ➡ For future work, we will compare our DNN models' performance against SVR and Random Forests.

Acknowledgements