Machine Learning for Soil and Crop Management
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Lecture 30
Use of ML for Portable Proximal Soil and Crop Sensors (Contd.)

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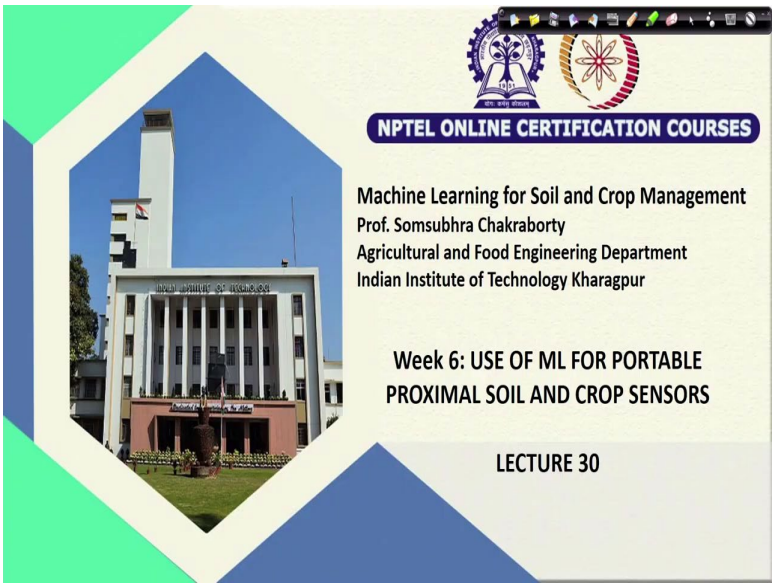

Welcome friends to this thirtieth lecture of this online NPTEL online certification course of Machine Learning for Soil and Crop Management. And this is the last lecture of week 6. And in this week, we are talking about use of machine learning algorithms for portable proximal soil and crop sensors.

In our first four lectures, we have discussed the details about the proximal sensors their classification, and then we have discussed about the portable XRF, portable x-ray fluorescence spectrometer their application for soil, crop. And also, we have seen the sensor fusion where we are combining more than one sensor together or sensor data together using different approaches simple merging.

And also, sometime model leveraging, model fusion for predicting, for better prediction of several soil properties. In our last lecture, we have started discussing about Nix colour sensor. And in this week, we will start from there and discuss more about Nix.

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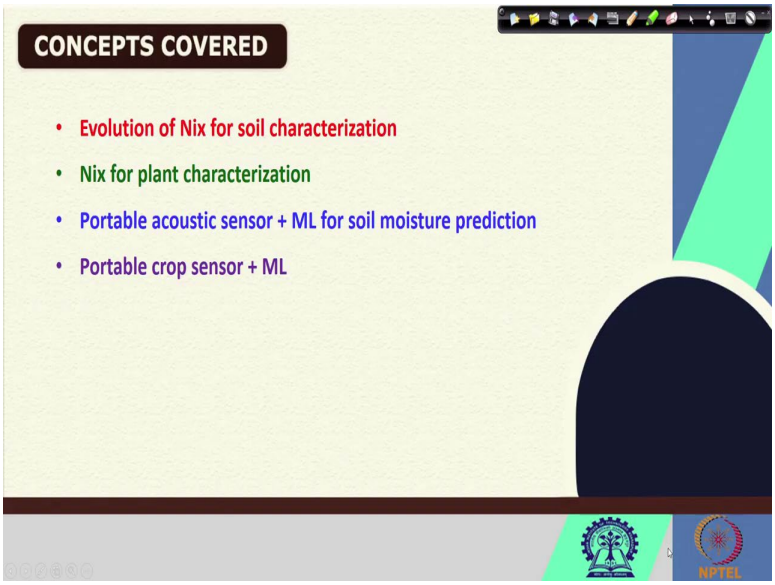

So, the these are the concepts which we are going to cover in this week. First of all, we will be talking about evolution of Nix for soil characterization, then we will also see one example where Nix is used for plant characterization. Third is portable acoustic sensor and machine learning for soil moisture prediction we are going to see. And then the portable crop sensor plus machine learning application we are also going to discuss.

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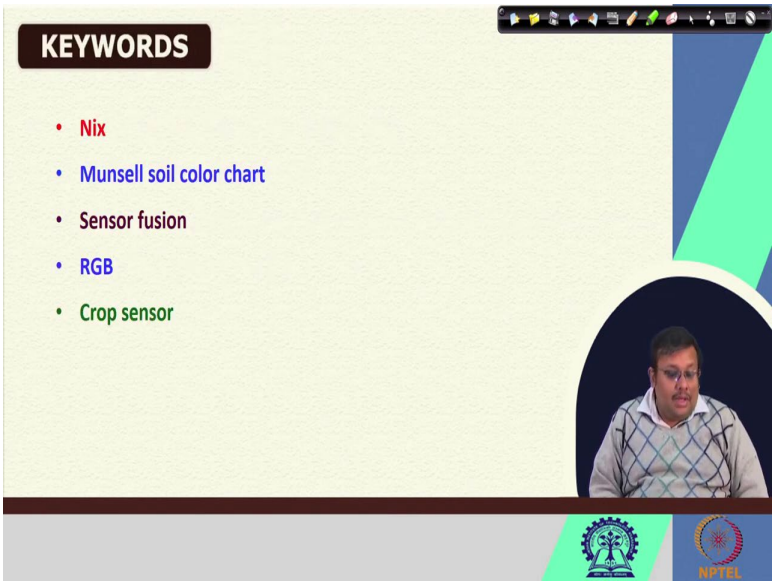

So, if you see the keywords which we are going to discuss. So, these are the important keywords for this lecture, Nix, Munsell soil colour chart, then sensor fusion, RGB and crop sensor.

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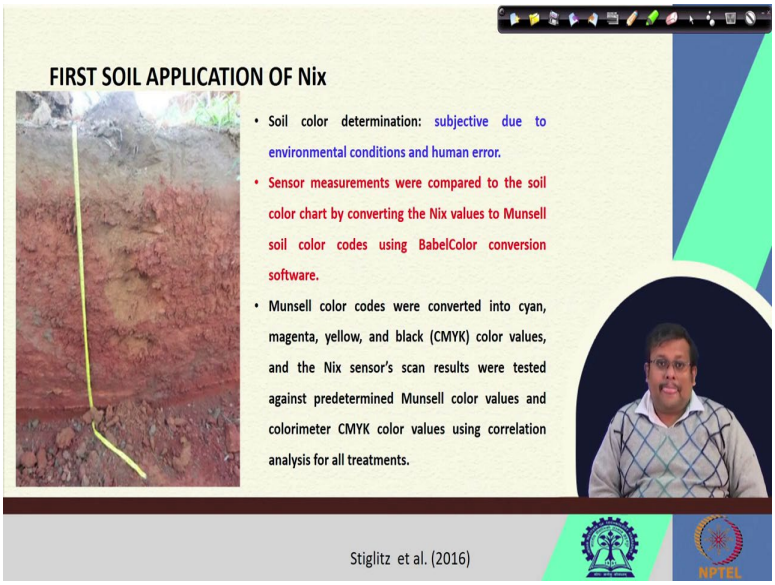

So, I have already discussed that the Nix sensor which is actually available in the in the market initially for colour, purity of the colour, for checking the purity of the colour. It was first exploited by a group of scientists, as you can see, they started applying it for different types of soil colour determination and subsequent prediction of soil properties.

You know that soil colour is a very important property which gives us the indication or variation of several elements, soil organic matter and also gives us the indication of different paedogenic processes. Now, so far, the soil colour description was based on the Munsell soil colour chart. Now, this soil colour chart has three variables they have different types of chips.

And in these chips, there are three variables hue, value and chroma. So, using this hue, value and chroma we can qualitatively describe the soil colour in the field or in the lab. However, this qualitative description of soil colour is subjective due to environmental condition and human error. Sometime we have seen that although some experienced petrology start defining the soil colour, they do not agree while describing the soil colour qualitatively.

So, it was important to use certain portable tools which can offset this disagreement of qualitative colour description. So, that is why the application of Nix started in the soil science domain. So, the first application was seen in Stiglitz et al. in the year 2016. Where sensor measurement were compared to the soil colour chart by converting the Nix values to Munsell soil colour codes using Babelcolor conversion software.

So, they collected soil samples and then they scan the soil using this Nix sensor. And the Nix extracted colour values were converted to Munsell soil colour codes using Babelcolor

conversion software. And also, the Munsell colour codes were converted into another colour model called cyan, magenta, yellow and black or CMYK colour model.

And the Nix sensor scan results were tested again pre-determined Munsell colour values and colorimeter CMYK colour values using correlation analysis for all treatment. They have tried the scanning both in dry soil as well as moist soil. So, they scan the soil both using Munsell soil colour and also using a standard colorimeter. So, they compared the results of Nix with the standard Munsell soil colour chart as well as the colorimetric results.

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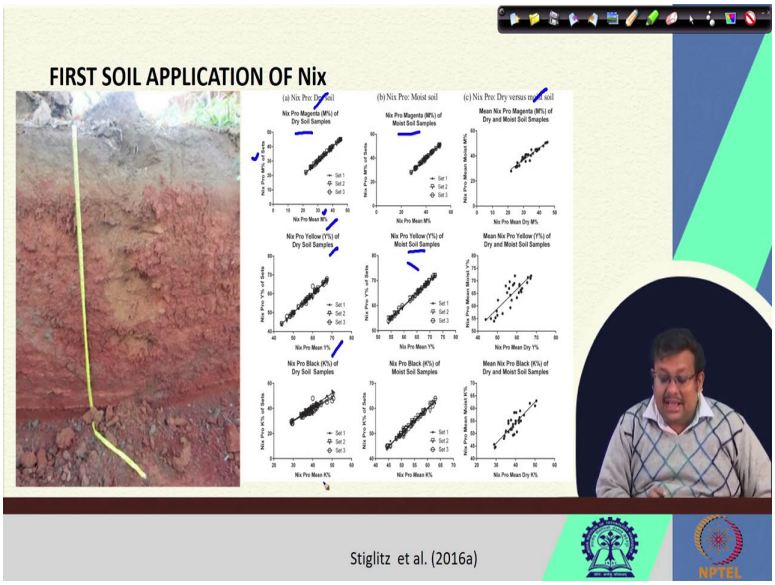

And they have showed that this Nix colour sensor has sufficient potential for qualitatively for quantitatively describing the soil colour. And these graphs are showing the relationship between the different indices, different colour model parameters, like you can see here, M, then mean M, Nix Pro mean M percent, Nix Pro mean M percent for sets.

So, and also you can see here for moist soil samples, and they have tried it for dry soil samples and moist soil samples, they have tried for magenta, they have tried for yellow, they tried for black also for both dry soil samples and moist soil samples. And they tried to compare the results between the between the moist soil samples and dry soil samples results. So, we can see that they have utilized this sensor variable. And they have utilized and they have established the potential of Nix colour sensor for prediction of soil colour.

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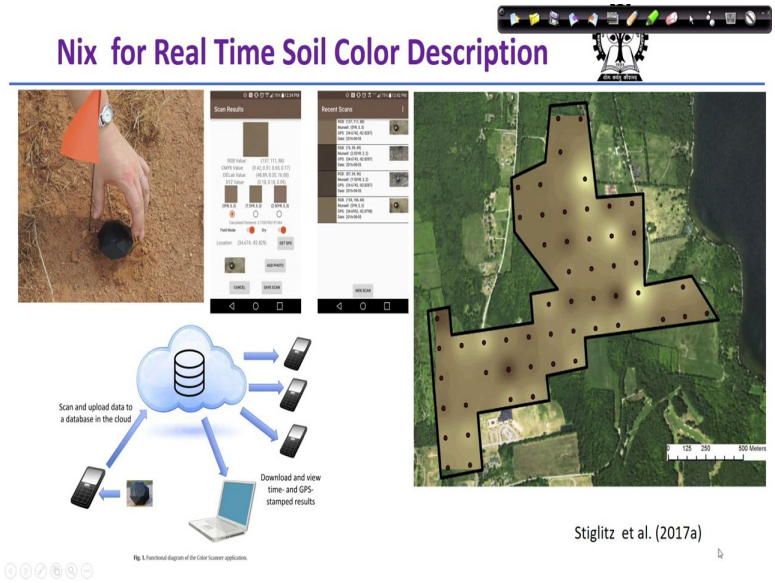

Not only that, in his subsequent research, they have developed an Android app and they have used it for real time soil colour description. So, they have converted these scan results into using an app to the Munsell soil colour values. And not only that, they also using these app, they have also uploaded scanned and uploaded the database into the cloud and downloaded the results to view in the time and GPS temperature so that they can create this real time soil colour-based map.

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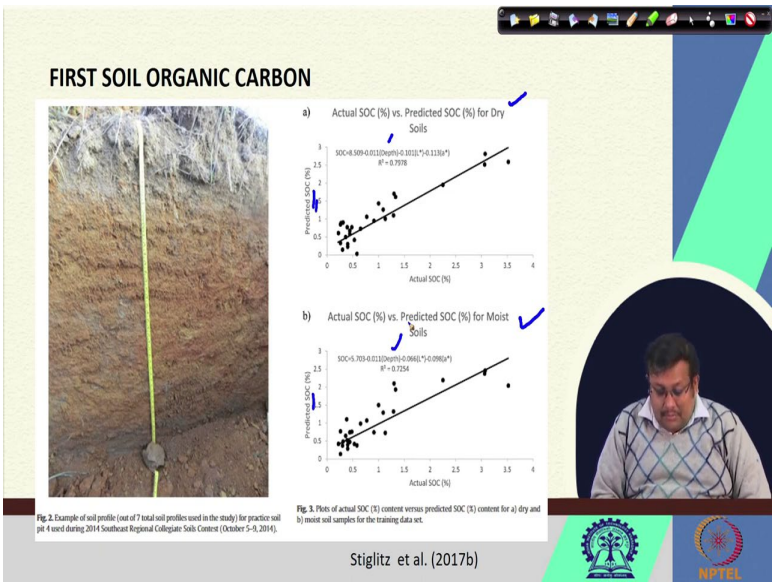

It does subsequent research in 2017 they have used this Nix colour sensor for prediction of soil organic carbon and that was a very important paradigm shift as far as the Nix based soil property predictions are concerned. So, they scan the soil samples in both dry condition as

well as the moist condition. And then they tried to predict the soil organic carbon using, as you can see here, they try to predict the soil organic carbon in both this condition, this is for dry soil and this for moist soils.

And they have proved the sufficient utility of this Munsell soil colour, for this Nix soil colour parameters for predicting the soil organic carbon. However, in these cases, they have also used depth as soil data as an auxiliary parameter for predicting the soil organic carbon. So, that was the first application, one of the first application where these Nix was used to predict the soil organic carbon through a prediction model.

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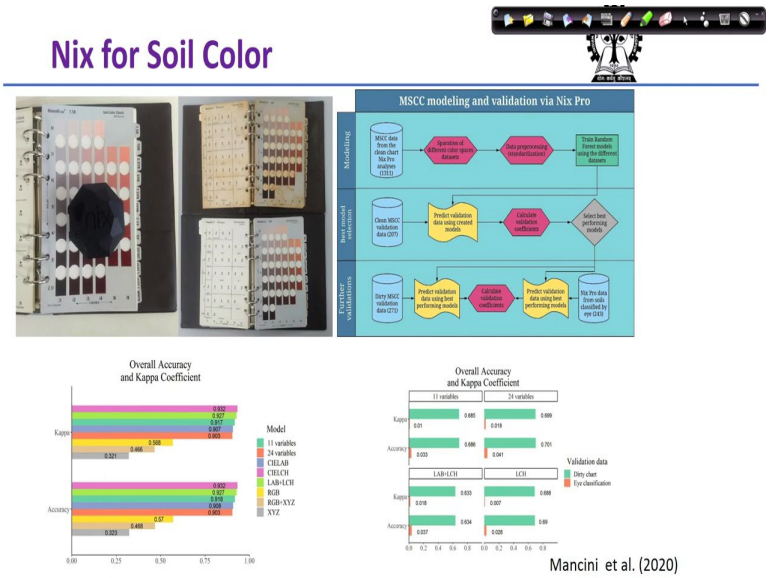

Subsequently in Brazil, Mancini et al. in 2020 they have showed the potential of Nix for classifying the Munsell soil colour chart. So, this is the Munsell soil colour chart as you can see, they are consisting of several colour chips and qualitatively generally a soil is matched with these colour chips and the best match colour chips and their rotation is basically designated as the colour of the soil.

So, these scientists group tried to replace the use of this Munsell soil colour chart by using this Nix and they have showed that yes, it is possible to predict or classify the Munsell soil colour chart notations using this Nix colour sensor. They have used different models, different machine learning models for classifying the Munsell data and they have established the utility of Nix.

So, you can see that the use of the simple, how the use of simple statistical model to higher machine learning model has helped the establishment of Nix based soil colour and soil property characterization.

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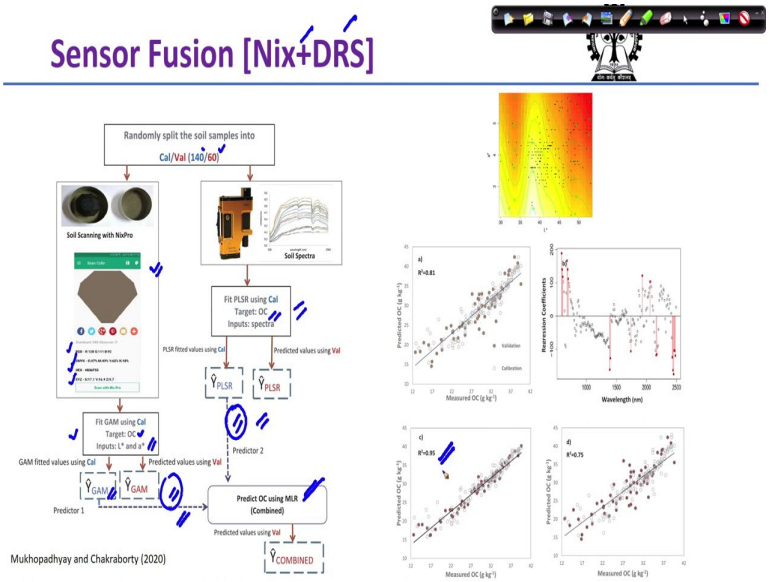

In a latest study, one of my PhD student has again developed a sensor fusion technology where she has showed that, she has showed that the combination of Nix colour values and DRS can produce better prediction accuracy for soil organic carbon. So, in this research we divided we collected 200 soil samples and we divided them into 140 calibration samples and 60 validation samples and then we scan them using Nix colours scanner.

And you can see this is how these Nix scan results will be appearing. So, they produce the results in RGB, CMYK, and then Hex colour codes, and XYZ and so on so forth. So, using these codes, we first fit the generalized additive model to predict the organic carbon where the inputs are only L and A parameters, because previously Stiglitz has produced the evidence that these two colour parameters are more related to organic carbon.

So, we used only these two and fitted this generalized additive model. And subsequently using the diffuse reflectance spectroscopy, we also predicted the organic carbon. So, in both these cases, we got the results using the calibration values, predicted calibration values in both these cases. And then we combined we use them as a predictor to and have them combine these two sets of predictors using the multiple linear regression model to predict the organic carbon.

So, these sensor fusion shows that when we combine this Nix and DRS together that produces better results. So, here you can see some examples where we are using the Nix data alone that produced somewhat around 60 percent prediction accuracy. And when we use the DRS spectra alone that shows around 80 percent accuracy, but when we combine this Nix and DRS by following this scheme, then we got these 95 percent accuracy. So, that shows that not only DRS plus PXRF but also Nix plus DRS has also the potential for producing better prediction results for several soil properties.

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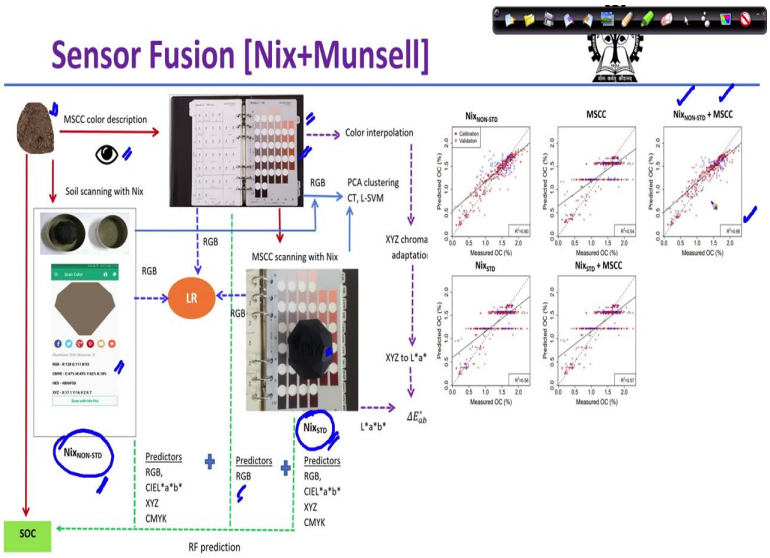

So, in another research, we tried to relate the Nix colour with the Munsell soil colour. And then we also tried model fusion by combining the Munsell soil colour values with the Nix values. So, here what we did, we collected the samples after collecting the samples we first visually describe the soil colour using the Nix, we using the Munsell soil colour chart. And also, simultaneously we scan them using the Nix sensor.

And once we defined the colour based on our visual description based on this Munsell soil colour chart, the same chips were again scanned using this Nix sensor. So, the resulted values of Nix were called the standard Nix values. And these non-standard Nix values are basically those Nix values which you have collected without comparing the Munsell soil colour chart.

So, the results from both non-standard Nix and also the standard Nix values and also the RGB values which are extracted from these Munsell soil colour were combined in different combination and then we tried to predict the organic carbon. We have seen that when we combine the non-standard Nix values with the Munsell soil colour chart extracted colour parameters, we are getting the highest r square validation r square.

So, that shows that there is a benefit of combining the Munsell soil colour extracted colour parameters, quantitative colour parameters. As well as the normal Nix can stand Nix results, and when we combine them together, they produce better prediction accuracy for organic carbon.

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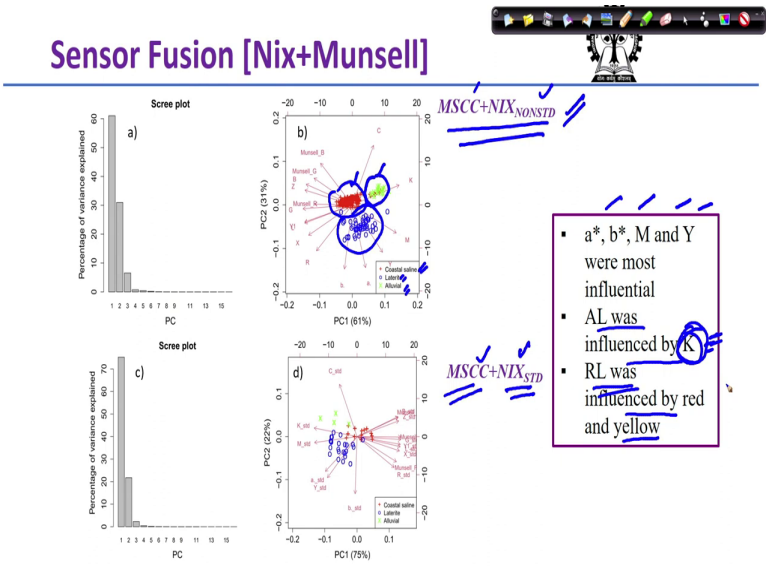

Not only that, when we combine these Munsell soil colour values with the non-standard values and Munsell soil standard values and standard values and we try to classify soil samples coming from different agroclimatic zones showing different colour properties. We can see here, when we combine these Munsell soil colour, with the nonstandard Nix, we can get better classification, we can clearly see the classification boundaries or clusters of these samples coming from three different agroclimatic region.

And here also, but where we are using the standard Nix values and Munsell cell colour values, we also got good clustering, but there are some Nix things. So that shows the relative superiority of using these non-standard values of Nix and also the Munsell soil colour chart. So, there are two different types of soil samples, one were collected from coastal saline zone of West Bengal, another is red and laterite soils, another one is alluvial soil. And these are the colour parameters which were most influential in this clustering.

And also, we can see that these AL soil was influenced by these K from CMYK which was expected because these alluvial soils are dark in colour. And this K basically shows the black or darkness of the soil colour. And RL was influenced by, red and laterite soil was influenced by red and yellow, which is also expected because these red and laterite soils are dominated by oxides mineral which are imparting the red and yellow colour of the soil. So, realistically,

we have seen that combination of these sensors can produce better results that using the individual sensor alone.

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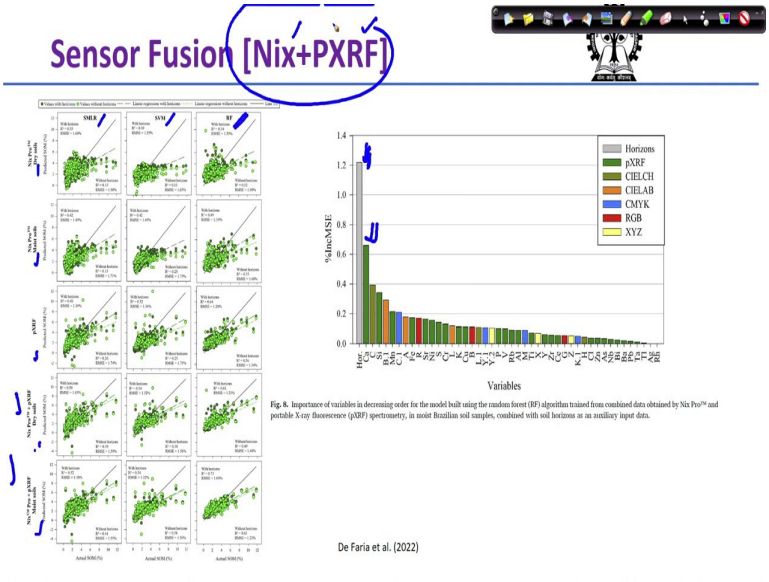

Now, in another research De Faria et al. in 2022, this year they have produced or proved the evidence that when we combine the Nix and PXRF together they produce better prediction accuracy for soil organic matter when we combine the depth of the soil that sometimes increases the prediction accuracy. So, they have tried three different model stepwise multiple linear regression model, support vector machine and also random forest.

And you can see here this is for the dry soil, this is for moist soil. These are the models for only PXRF. These are the models using Nix plus PXRF was dry soil. And here, Nix plus PXRF for moist soil. So, for all these conditions they have combined, they have produced the sensor fusion. And specifically, here these are the sensor fusion results and they compare the results with a single sensor-based model and they found that among all these.

And also, they have combined this soil horizon depth as an auxiliary variable. And this is the random forest variable importance plot, from this plot it is evident that this horizon and also this calcium are to PXRF measured calcium and the horizon depth are two major influencing factor for producing the better prediction accuracy. So, that shows that a combination of Nix and PXRF along with the auxiliary predictors like depth of the soil can help in better prediction of soil organic carbon.

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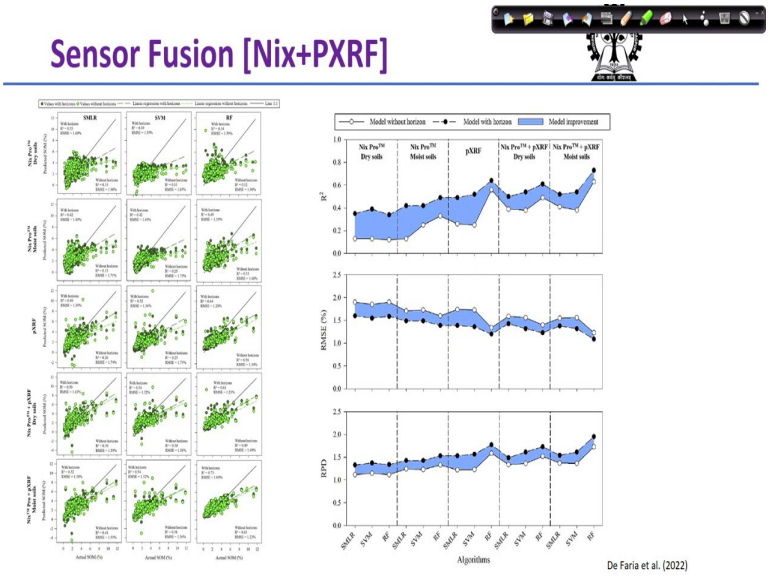

So, they have also showed here the r square values, RMEC values, and RPD values. And they have compared the results between the fused model as well as the individual sensor-based model.

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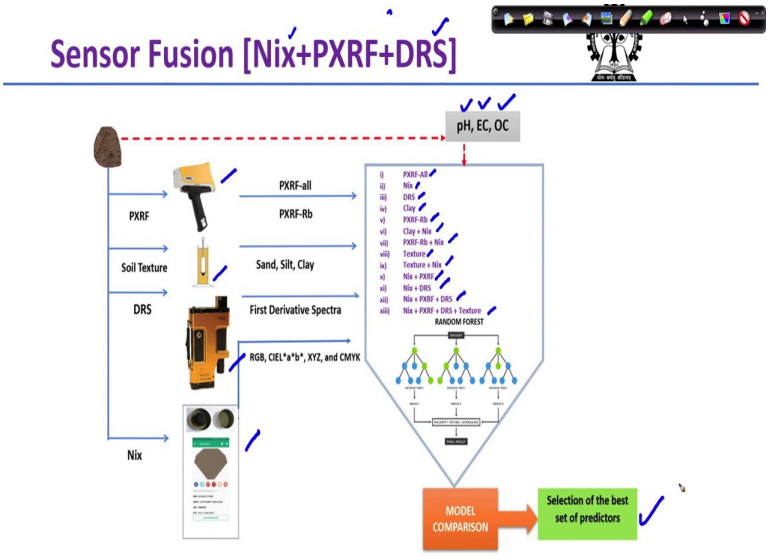

In a recent exercise and research, one of my students has also combined the three different sensor together and using the machine learning model. So, here you can see Nix, PXRF and DRS were combined together and ultimately different, 13 different combinations like using PXRF alone, the Nix data alone, DRS spectra alone, only clay content, then PXRF measure rubidium content as a proxy for clay, the clay plus Nix, then PXRF-RB plus Nix, then soil

texture that is sand plus silt plus clay, then texture plus Nix, the next plus PXRF, Nix plus DRS, Nix PXRF DRS, and Nix PXRF DRS plus texture.

So, all these 13 combinations were tried to predict these pH, EC and OC and we combine the data from this PXRF soil texture results, Nix as well as DRS. And then we compare the model accuracy and select the best set of predictors.

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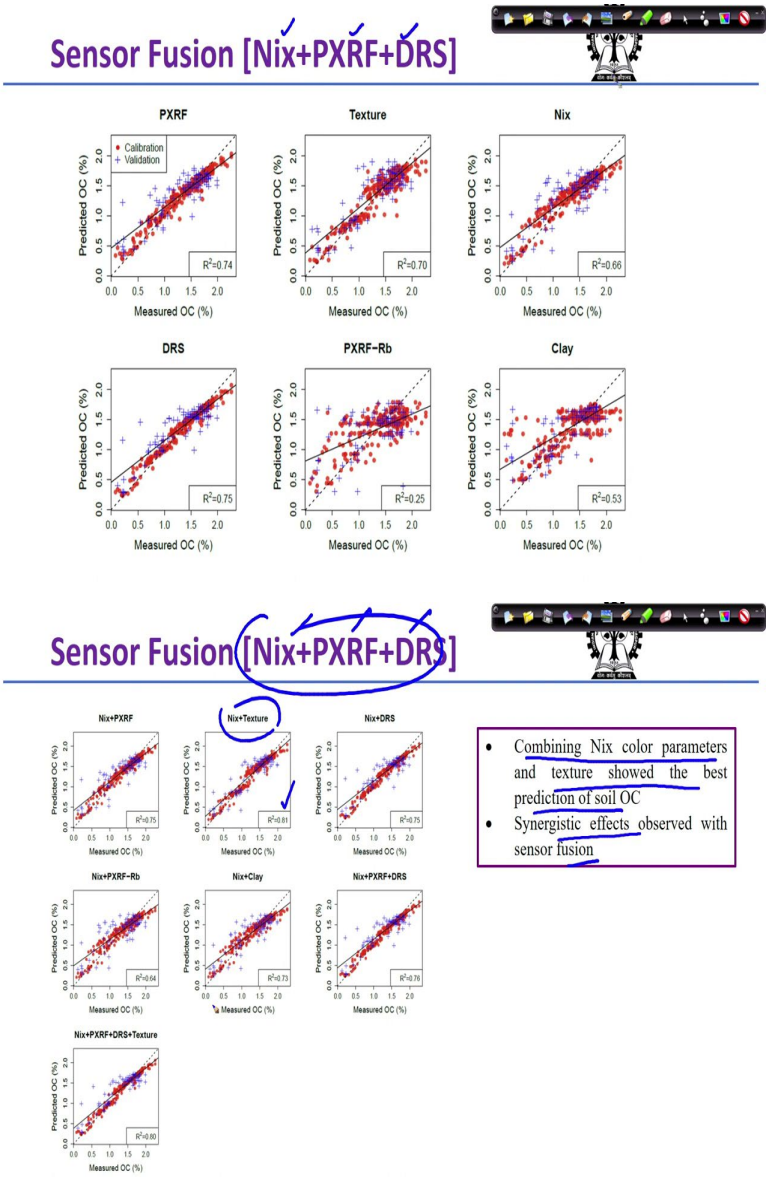

So, the result shows that when we combine the results for using this Nix PXRF DRS. For organic carbon prediction, we can get the best results when we are combining the Nix with the, we can get the best results when we combined the next plus texture where we are getting the r square values, in addition r square values of 0.181. So, basically, we see that combination of Nix colour parameters and texture showed the best prediction for soil OC.

And we can see the synergistic effect observed with sensor fusion. However, for other parameters, we have seen the combination of Nix PXRF DRS produce the best model prediction. So that shows the importance of model fusion or sensor fusion for prediction of best results. And these are all random forest model. So, that shows the importance of machine learning also for predicting these different parameters or establishing the benefit of model a sensor fusion.

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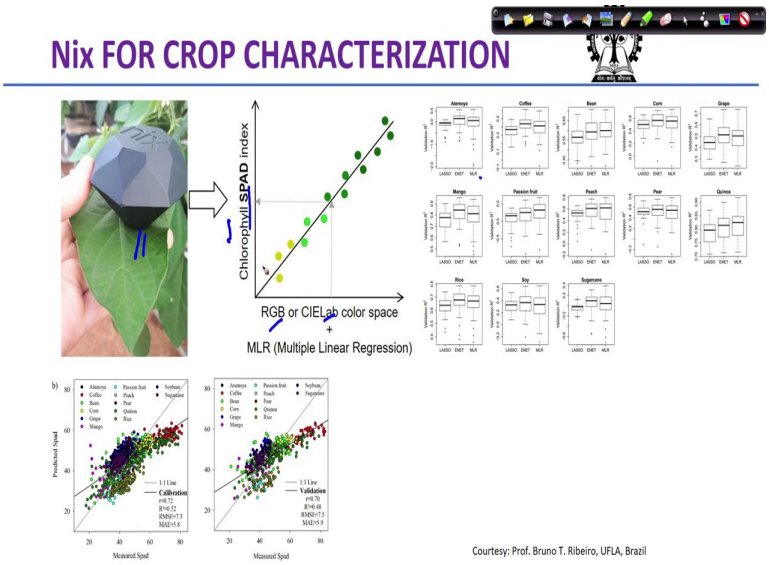

So, so far, we have seen the application of Nix for soil characterization. Recently in our research, in collaboration with Professor Bruno Ribeiro of Brazil, we have seen that if we can use this Nix to extract the colour of the leaves for different plants, we can predict the chlorophyll Spad index. Now, chlorophyll SPAD index indicate the nutrition, status of the crop.

And if we extract these RGB, or CIELab model colour space model and then combine them together using the multiple linear regression, we can produce better prediction for this chlorophyll SPAD index. Which may help in real time monitoring of crop health status. So, we have compared different types of model, multiple linear regression model, elastic regression model and the Lasso model.

And we have found that yes, it is possible to produce better results when combining these Nix with different types of prediction model for real time monitoring of crop health status. So, that shows the expansion of Nix application from soil to crop and further research is necessary for enhancing its application for other crop properties also.

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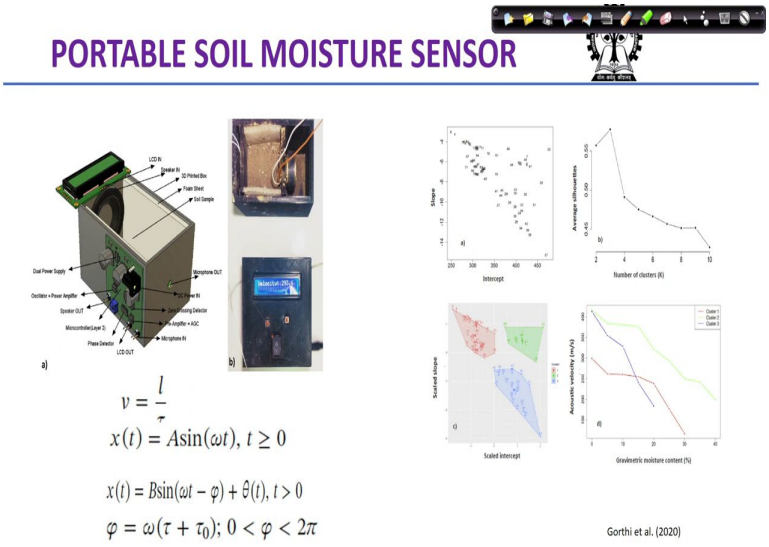

We have also seen the use of machine learning for portable soil moisture sensor, the soil moisture sensor has been developed by one of my students, which is based on the acoustic velocity and this is the sensor, this is the real sensor. And in this real sensor, there is an acoustic source, there is a speaker and in other side there is a detector and the soil is packed inside the speaker at detector.

And the time of flight from the speaker to the detector of sound is basically utilized to produce or predict the soil moisture content and for establishing the utility of the sensor we have also used extensively the machine learning model like linear mixed effect models. So, not only for soil fertility parameters or crop parameters, these machine learning models can be also combined with different other portable sensor for soil moisture measurement also, real time measure measurement also.

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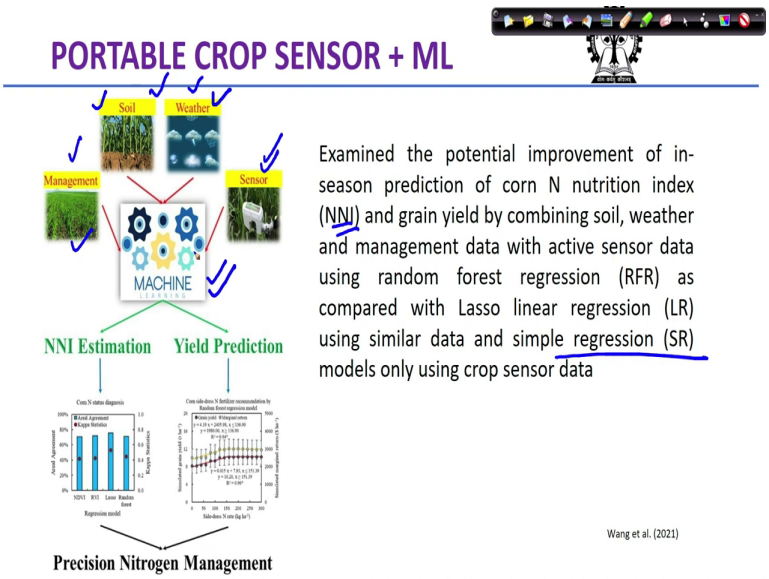

So, this is another application we have seen where portable crop sensor was used in combination with machine learning for precision nitrogen measurement, management in the crop. So, these Wang et al. this scientists group in 2021 they have examined the potential improvement of, insisted prediction of corn nitrogen nutrition index, they call it NNI and grain yield by combining soil data as well as weather data, management data along with the active sensor data, green seeker.

So, these active sensor data with random forest regression which is a machine learning tool, as compared with the Lasso linear regression and using similar data and simple linear regression models for. So, basically, they have combined this management data, soil data, weather data, sensor data using random forest and they compared with the Lasso linear regression using similar data and simple linear regression model using only the crop sensor data.

So, they predicted the results, they utilize, they established the use of these portable crop sensor data and machine learning data together for better precision nitrogen measurement.

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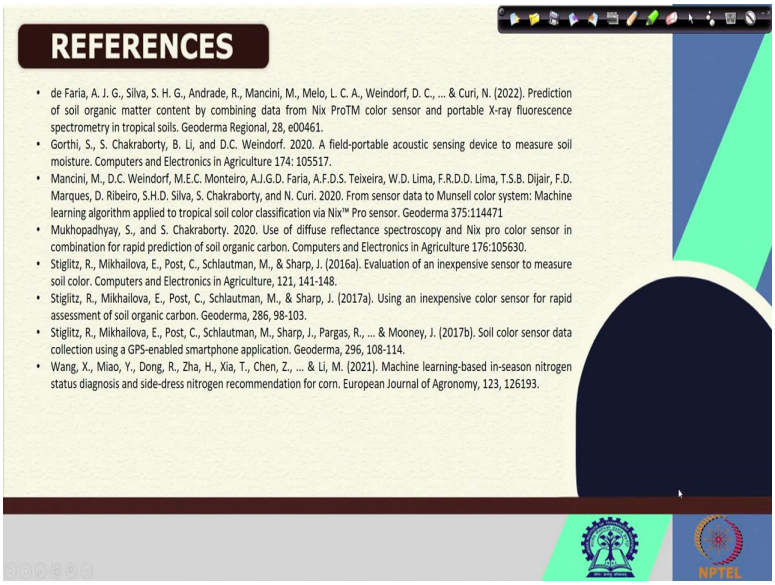

So, there is a here we wrap up this lecture. And this week, of course, I have tried to show you these advancements in crop and soil sensors and their application for prediction of different soil and crop properties. In combination with different machine learning models. Of course, these are producing some overviews, but I have mentioned these references so that you can go back and consult these papers for better understanding of what is actually going on. So, you feel more and more confident of using this type of machine learning algorithms with your crop and soil data for better soil and crop management strategies.

So, let us wrap up our week 6 here, and in our next week, we will be talking about a very, very important aspect of machine learning based soil and crop management that is image and image-based, image processing and their subsequent use with machine learning for soil and crop management. So, thank you guys for joining and let us meet in our week 7 lectures.