Analysis of Optimum Crop Cultivation Using Fuzzy System

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Abstract— **In this paper we have proposed a system that will be able to analyze the Optimum Crop Cultivation of Bangladesh based on the knowledge of Neuro-Fuzzy System (NFS). The Neuro-fuzzy system is the collection of two techniques: fuzzy logic and the neural network. The system can compute the yield of a certain crop by using the value of humidity, temperature and rainfall. By using this system farmer will be able to increase agricultural productivity. Hence, this will have an overwhelming impact on poverty alleviation, boosting employment rate, human resource development and food security. The dataset that we used to train our system was collected from the official website of Bangladesh Bureau of Statistics. It contains the humidity, temperature and rainfall values of thirty-three districts of Bangladesh that produced the most crops from the year 2007-2013. We considered a few major crops of Bangladesh, i.e., Rice (Aus, Amon, Boro), Wheat and Potato. By using this system, farmers can harvest maximum production of crops throughout the various seasons in the year.**

Keywords-Fuzzy logic, neuro-fuzzy system, cultivation, Matlab, GPS, ANFIS

I.   INTRODUCTION

Bangladesh is the ninety-third largest country by area and also astoundingly the eighth most populated country in the world [1]. Due to this dense population most of the area is used for housing and industrial purposes whereas less is used for cultivating crops. So it is very much important for Bangladesh to utilize this area efficiently as much as possible for cultivating crops.

According to [2], crop cultivation was a major part of Bangladesh's Gross Domestic Product [3] till 2010 but after that it has dropped by 18% which indicates that the sector needs more attention and support to regain its healthy position in the Gross Domestic Product [GDP]. To support the large population of Bangladesh we need more crops. However, if the production of crops goes down then we have to import crops from outside the country which will cost more and would not feasible for a developing country like Bangladesh.

Every year crops gets damaged due to countrywide flood and other natural disasters [4]. So it is very important that rest of the month farmers need to ensure maximum production of crops. They need to decide which crop will have the best production if planted at that time. To help them in the decision making process we proposed a system in this paper that will be able to help them plant crops using the openly available data from Bangladesh Bureau of Statistics (BBS) [5].

BBS provides the government with statistical data for proper decision making. It has reached a lot of milestone but the system is not yet fully capable of analyzing the data to its optimum level [16]. Therefore, we tried to implement a neuro-fuzzy inference system that might improve the capability of our decision-making. We worked with agricultural annual data that was collected by the BBS from annual or seasonal conducted surveys. The dataset contain the humidity, temperature, and rainfall, estimate of acreage, production, and yield, crop losses caused by floods, annual land utilization, and annual weather and crop reports by districts.

We arranged the paper as follows: related works are described in Section II. Section III presents the methodologies containing the manipulation of dataset, ANFIS training and its results, Section IV portrays the conclusion and finally Section V discusses about our future works.

II.   RELATED WORK

Analysis of optimum crop cultivation is basically designed in such a way that farmers can produce more crops with less resources and farming land. Besides, it is important to ensure the scalability, efficiency and reliability of the system. In this regard, fuzzy system, a state-of –the art technique and effective approach to deal with imprecise, ambiguous and unpredictable data, has made the process effective and very accurate.

In paper [6] the authors have mainly focused on land suitability classification based on farmers' knowledge by deriving 12 distinct FK rules. For this purpose, the western part of Nizamabad

district in India was selected as study area where approximately (70-75) % of total lands are used for agriculture. The degree of similarity between FK-derived map and LRDP map was in range from 40% to 73%. Therefore, in this paper FK rules are suggested to use integrated with GIS in order to obtain optimum land use planning.

Paper [7] also worked on land suitability, but the approach here is Multiple Criteria Decision Making (MCDM). The research area was Takestan and was divided into 8 characteristics of land and 13 land units to apply AHP (Analytic Hierarchy Process). In AHP, a normalized pairwise matrix can be obtained by organizing all the factors in a hierarchy along with their sub-factors. In this research, yield of wheat in the mentioned region was observed and compared with the results obtained from both parametric and fuzzy approach, in which the fuzzy method proved to be more accurate. In order to ensure precise farming, research [8] applied fuzzy cognitive map on cotton yield management. After construction of maps, NHL algorithm has been applied to train the dataset in order to obtain the accurate yield prediction in ranges between high and low.

Since soil erosion of agricultural land cost huge loss for farmers, in [9], soil shear strength has been predicted by using three different approaches: ANFIS (Adaptive Neuro Fuzzy Inference System), ANN (Artificial Neural Networks) and MLR (Multiple-linear Regression). The methods have been applied on different soil samples and ANN model predicted the strength more accurately than the other two. Since MLR needs larger dataset than ANN and ANFIS, it becomes difficult to build maintainable regression model. This paper suggests that ANFIS is not always the best approach to predict soil shear strength.

Paper [10] used fuzzy algorithm on global data set to estimate marginality of different regions and identify unused lands so that agricultural lands are not over used. In [11], authors have considered few agricultural related indicators in order to evaluate cultivation system such as cropping and farming. Khosnevisan et al. [12] evaluated both traditional and consolidated rice producing farms using life cycle assessment as well as fuzzy model. On the other hand, life cycle assessment (LCA) methodology has been used where each and every step of life cycle is used. The core target of the project [13] is predicting yield crop production using ANFIS. Actually, this is a model what predicts wheat production. In this process, different parameters such as soil condition, biomasses etc. are used as input to ANFIS. In contrary, the only output is the yield production.

Dacid B.Lobell et al. [14] have designed a precise and effective model to estimate crop yield in terms of climate change. Broader approaches using statistical data have been used in this model. However, simulated observation and regression analysis methodology have led to design the model. On the other hand, yield responses to different temperatures and precipitation are being simulated with CERES-Maize, which gives various results in the developing the model. Overall, although few factors that can affect the statistical model are not considered here, this model can help to predict yield crop production being responsive to climate change.

III. METHODOLOGY

A. Selecting input attributes from Dataset

The dataset we acquired is openly available to all from [15]. The data we initially contains the temperature, humidity, rainfall for all twelve months from 2007 to 2013. Figure 1 contains the humidity chart for the year 2013 for illustration purpose.

The dataset also had information about yields of the major crops in a yearly basis. The yields were given in mounds per acre and metric tons per hectare as shown in Figure 2.

District	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Barisal	79	76	75	75	86	84	87	87	88	87	80	82
Bhola	78	73	74	76	86	84	87	89	87	86	80	83
Bogra	76	67	63	75	81	79	81	85	82	83	78	76
Chandpur	77	70	70	76	85	82	85	86	85	84	75	79
Chittagong	72	64	77	77	85	84	84	86	84	85	78	77
Chuadanga	79	74	65	65	81	84	86	87	87	88	82	82
Comilla	74	68	75	78	85	81	83	85	84	85	78	81
Dhaka	65	55	55	63	78	76	77	80	81	78	66	72
Dinajpur	78	69	64	69	80	81	82	85	81	85	74	75
Faridpur	76	69	65	68	84	82	83	85	85	85	76	79
Feni	77	70	72	76	86	83	85	86	86	86	79	80
Hatiya	76	70	76	80	86	86	88	90	88	88	81	82
Ishurdi	81	74	63	63	81	83	82	85	84	85	78	81
Jessore	77	71	65	67	79	81	82	84	84	85	75	78
Khepupara	71	65	72	78	85	84	86	86	88	88	78	78
Khulna	83	77	70	71	82	84	90	91	85	86	75	78
Kutubdia	81	80	81	87	87	89	89	88	88	89	77	76
Madaripur	79	72	71	76	86	84	86	86	86	86	77	82
Maijdee Court	73	67	71	75	85	82	86	87	85	85	76	80
Mongla	74	67	70	73	83	85	87	87	86	87	77	79
Mymensingh	78	70	74	77	84	82	83	85	85	85	81	82
Patuakhali	77	71	73	77	87	86	89	89	90	89	79	81
Rajshahi	79	74	64	62	80	83	83	86	84	86	76	80
Rangamati	75	62	63	68	79	82	83	85	84	86	82	82
Rangpur	80	72	66	70	82	81	81	84	82	83	77	80
Saidevpur	78	69	64	70	82	82	85	84	85	82	84	79
Sandip	74	68	76	77	86	84	85	88	88	87	80	83
Satkhira	76	72	71	70	80	81	82	85	85	83	76	79
Sitakunda	75	70	76	78	86	85	85	88	87	85	78	81
Srimangal	79	72	67	72	83	82	83	85	85	85	81	83
Sylhet	74	62	60	69	83	81	83	85	83	81	74	75
Tangail	79	73	67	68	81	80	81	84	83	84	77	81
Teknaf	64	62	74	77	85	87	89	87	87	84	78	71

Figure 1. Monthly Humidity Record of 2013

	Zila/Region	2011-12					2012-13				
		Area		Yield per		Production	Area		Yield per		Production
						(M.Tons)					(M.Tons)
		Acres	Hectares	Acre (Maunds)	Hectare (M.Tons)	(M.Tons)	Acres	Hectares	Acre (Maund)	Hectare (M.Ton)	
1	Bandarban Region	1021	413	103.42	9.54	3942	634	257	126.2	11.641	2987
	Chittagong	8977	3633	144.66	13.343	48474	9179	3715	135.53	12.501	46436
	Cox's Bazar	1439	582	145.78	13.446	7830	1176	476	110.35	10.178	4844
2	Chittagong Region	10416	4215	144.81	13.358	56304	10355	4190	132.67	12.237	51280
	Comilla	31106	12588	224.73	20.729	260940	34228	13851	192.71	17.775	246210
	Chandpur	28125	11382	240.35	22.17	252327	31394	12704	206.76	19.071	242293
	Brahmanbaria	7190	2910	167.53	15.453	44963	4902	1984	154.5	14.251	28270
3	Comilla Region	66421	26879	225.15	20.768	558230	70524	28540	196.31	18.107	516773
4	Khagrachari Region	953	386	114.4	10.552	4070	975	395	107.11	9.88	3898
	Noakhali	465	188	84.23	7.769	1462	477	193	128.47	11.85	2287
	Lakshmipur	305	123	109.36	10.087	1245	296	120	108.88	10.043	1203
	Feni	505	204	112.99	10.422	2130	579	234	128.28	11.833	2772

Figure 2. Potato yearly production for some districts from 2011 to 2013

The red marked numbers in Figure 3 is what mostly interested us. Our main focus was to design a way to use them for our project. The numbers below 'acre (mounds)' refers to the mound (1 mound = 37.4 kilogram) produced per acre of that particular crop. The same principle applies for hectares (M.Ton) but in this case its metric ton produced per hectare.

B. Manipulation of dataset

Our main objective was to link yield with our possible inputs of humidity, temperature and rainfall. At first before joining input

with our output we linked the three inputs into one table. Then, we used a crop calendar and the yield table to determine where and when the crop in question can grow. Crop calendar tells the prime time for all crops cultivation as shown in Figure 3.
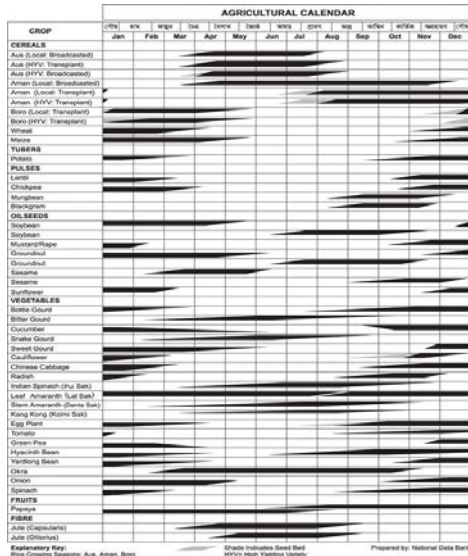

Figure 3. Crop calendar of Bangladesh

Using that we added the yield for each district divided into those particular months of production. For example, potato can grow from mid-September till the end of March the following year. Hence, we divided the yield to those six months and placed it into our data. This will grant us a table that can ultimately provide the possible yield using humidity, temperature and rainfall as inputs as shown in Figure 4.

No	District	Humidity	Temp	Rainfall	Yield Per Acre	Yield Per Hectre
1	Barisal	80	11.1	0	170.12	15.692
2	Bhola	80	11.6	0	170.12	15.692
3	Bogra	76	10.6	0	150.26	13.86
4	Chandpur	78	12.8	0	206.76	19.071
5	Chittagong	73	13.4	0	135.53	12.501
7	Comilla	77	11.1	0	192.71	17.775
8	Dhaka	68	12.4	0	207.9	19.177
9	Dinajpur	77	9.8	0	110.94	10.233
14	Jessore	77	9.9	0	65.73	6.063
21	Mymenshingh	82	10.7	0	76.17	7.026
23	Rajshahi	75	9.4	0	129.51	11.946
24	Rangamati	78	11.5	0	93.68	0
25	Rangpur	80	10.3	0	105.84	9.763
31	Sylhet	72	12.2	0	60.78	5.606
32	Tangail	79	10.1	0	90.04	8.305

Figure 4. Input table of January for potato

C. ANFIS

For the fuzzy inference system, we used MATLAB's fuzzy toolbar called 'Neuro-Fuzzy System'. For our goal requirements we had to calculate the production for all crops from the dataset we produced and supply the user with the crop that will yield the most. At first, we divided our datasets according to months for all crops, therefore we have a total of, 5 X 12 = 30 different datasets

Also, as the toolbar provided by MATLAB does not support two outputs, yield per acre and yield per hectare as in our case

therefore we decided to use 'yield per acre' as the output as both yield values are essentially the same. For example, for our basic operational purpose, we ran the system with some randomly picked months with all the crops.

1) Data Testing on ANFIS

We loaded our test data of all our crops for demonstration one at a time as shown in Figure 5. For our membership functions we used 5 primary values as small changes made in input resulted in different output and our goal was to get as accurate answer as possible. We used 20 epochs, 10 more than default, for our training purpose as we wanted to fit the data as properly as possible and recorded each of their surface curves with minimum error.
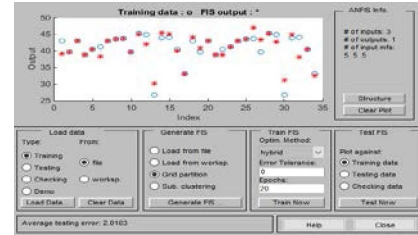

Figure 5. Training of Datasets

From our initial testing the average error ranges from 1 to 7 percent. For all the trainings we performed, in this case it was 2.0163% error. The system produced its own membership function which is discussed in the next section.

2) Membership Functions

Our primary objective was to consider the whole year as one dataset but according to our data it is nearly impossible to consider it as a whole. The fluctuations in data is in decimals from data to data but the range is huge. From what we have seen on the data, the small changes lead to different output values therefore if we wanted to implement the whole year as one we at least had to have 10 or above membership functions for each input. The type of computing and RAM requirement from the input is not supported by our standard computers. Therefore, we decided on a much simpler way by dividing the years into months. Our membership functions varied from month to month as the input's range and deviation of values changes according to the seasons. For example, in December or January rainfall is considered almost 0 throughout the dataset but in case of June and July, rainfall is at its peak. The range of rainfall is therefore not the same throughout the year. The membership function we got using the test for humidity, temperature and rainfall on the month of December is as shown in Figure 7, 8 and 9 respectively based on the triangular function as shown in Figure 6. Table I-III depict different parameters value for temperature, rainfall and humidity.

$$\text{triangle}(x; a, b, c) = \begin{cases} 0, & x \leq a. \\ \frac{x-a}{b-a}, & a \leq x \leq b. \\ \frac{c-x}{c-b}, & b \leq x \leq c. \\ 0, & c \leq x. \end{cases}$$

Figure 6. Triangular Membership function general formula

For all three inputs, we used 5 membership functions as any other combination of membership functions gives a result that is not proper according to our output. Triangular functions were used as it is easier to visualize and interpret in our eyes and also changing the shape type didn't change the results in any sort of way for our dataset. The membership function plots are shown on Table I, II and III which are plotted using the membership functions as listed above. The functions look almost identical except their ranges.

Humidity – [72 - 88]
Temperature – [11.5 – 17]
Rainfall – [0 – 5]

These ranges are for the month of January and could change drastically for any different month.
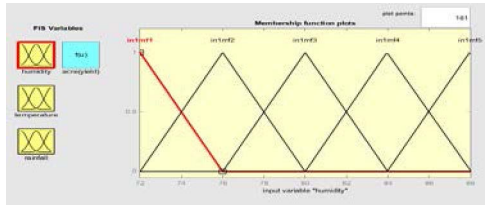
Figure 7. Humidity Membership Function on January

Table I. Parameters for Humidity

Humidity	Parameter	
	Function Type	*Parameter*
In1mf1	Triangular	a=72 b=76
In1mf2	Triangular	a=72 b=76 c=80
In1mf3	Triangular	a=76 b=80 c=84
In1mf4	Triangular	a=80 b=84 c=88
In1mf5	Triangular	a=84 b=88
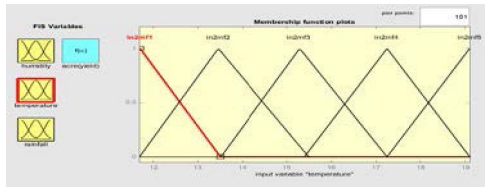
Figure 8. Temperature Membership Function on January

Table II Parameters for Temperature

Temperature	Parameter	
	Function Type	*Parameter*
In2mf1	Triangular	a=11.5 b=13.5
In2mf2	Triangular	a=11.5 b=13.5 c=15.5
In2mf3	Triangular	a=13.5 b=15.5 c=17
In2mf4	Triangular	a=15.5 b=17 c=19
In2mf5	Triangular	a=17 b=19
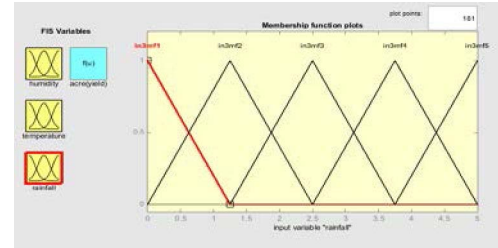
Figure 9. Rainfall Membership Function on January

Table III. Parameters for rainfall

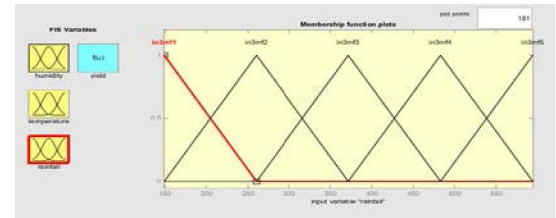| Rainfall	Parameter	
	Function Type	*Parameter*
In2mf1	Triangular	a=0 b=1.25
In2mf2	Triangular	a=0 b=1.25 c=2.5
In2mf3	Triangular	a=1.25 b=2.5 c=3.75
In2mf4	Triangular	a=2.5 b=3.75 c=5
In2mf5	Triangular	a=3.75 b=5

Figure 10. Rainfall Membership Function on August

An example for the month of August on the changes of membership function for rainfall is shown in Figure 10. We could clearly see that the range of rainfall changed from previous [0-5] to [149-594]. This change also alters the membership functions respectively.

3) Results

After running the system, the neural network we got is shown in Figure 11, this shows the rule-based combination leading to the output of our system. This can also be represented in a more interactive way as shown in Figure 12 where we can change the inputs and get the ANFIS output.
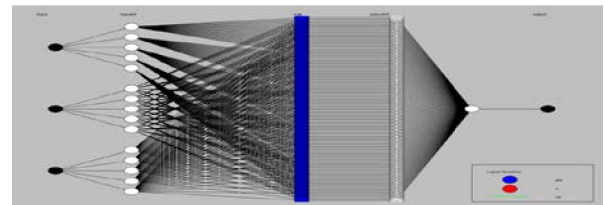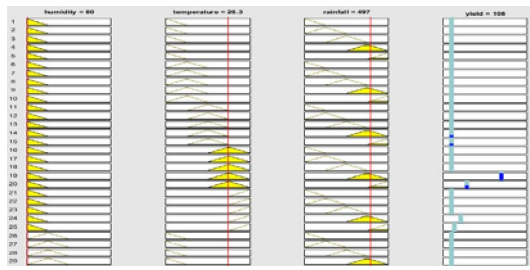

Figure 71. ANFIS structure

Figure 12. Rule View

From Figure 12 we can see that with an input of humidity=80, temperature=26.3 and rainfall=497, the yield is 108. The red bars are moved to the user's choice and the probable yield is shown to the user.

Before presenting the results, we ran through all the data in ANFIS and calculated the error percentage for all the crops, Figure 13 represents the average testing error for all crops.
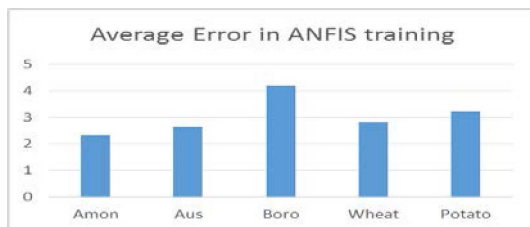

Figure 13. Error in ANFIS for all crops

We recorded all the surface diagram for comparison and some leads to easily distinguishable conditions for better yield as shown in Figure 14. From the diagram we can clearly see that lower humidity and little or no rainfall results in more potato in yield.
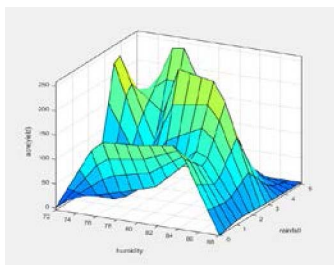
Figure 14. Humidity-Rainfall for Potato on January

Finally, our main objective can now be accomplished when we actually compare crops against each other. For our demonstration we used Boro and Potato and before diving into results we computed the testing error of the crops month wise as shown in Figure 15. Testing Boro yielded higher percentage error but the months we selected for testing (December and March) had lower percentage error for both crops. Therefore, the error would not affect the result in a significant way.
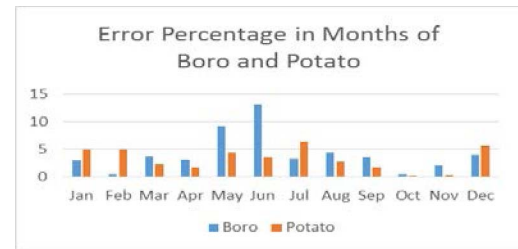

Figure 15. Error of Boro and Potato in months

We trained both crops on the same conditions and checked their yield as shown in Figure 16 and 17. On the figures we can clearly see that both boro and potato favors the same condition but potato clearly has 4 times more yield for that given period of time. Boro peaking its yield near 50 mound per acre and potato having nearly 210 mound per acre yield.
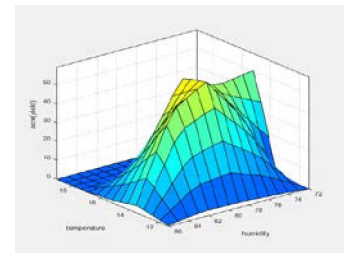

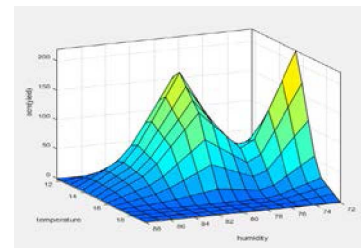*Figure 16. Temperature - Humidity of Boro on January*

Figure 17. Temperature - Humidity of Potato on January

Now when we perform the same experiment on the month of August the results are quite opposite as shown in Figure 18 and 19.
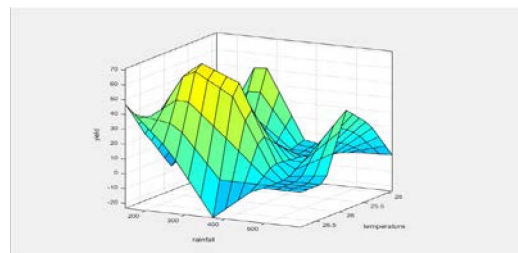

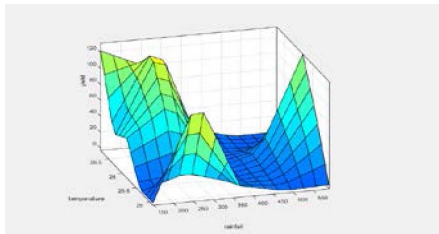*Figure 18. Rainfall - Temperature for Potato on March*

Figure 8. Rainfall - Temperature for Boro on March

This figures explains that on March due to the rainfall condition changing the production of boro as well as potato was changed. The production of boro is now much higher than potato. Even though potato is a crop that is very easy to grow, there are some conditions where it is better to grow another crop as it can have better yield according to the environment condition.

IV. CONCLUSION

Crop Cultivation is still the most important agricultural activity throughout Bangladesh despite its recent fall in the GDP. Out system successfully demonstrates the result of Potato and Boro for the month of January and August. According to our assessment, we have seen that even though in some time and area where potato can grow with much larger yield than Boro there are consequently time and areas where Boro can yield more. We believe the proposed system will be able to help farmers to take the right decision of cultivating the right crop. A farmer can plant different crops in different districts based on the system recommendation. So, every farmer will get the chance of maximizing their yield and profit by using the system. Our main goal is to produce more with less as even being a developing country; we are almost using all our resources to keep up to date with the rest of the world. In addition, any sort of contribution to the agriculture can be beneficial for the country as well to its people.

V. FUTURE WORK

In our future work we are planning to add all of the crops that are being cultivated all over the Bangladesh. This will make our system usable for the farmers of every district. The pH levels of the soil will be added to improve the accuracy of system for recommendation. The pH level measurement is important in the whole cultivation process as the pH level shows whether a crop need any treatment for better harvesting or not [17]. Also, the acidity of the soil in which farmers plan to cultivate on can be measured from the PH level. In future our system will also be able to recommend which crop will be more profitable to cultivate with respect to pricing per unit production. Suppose wheat has maximum production in an area whereas potatoes production is less than wheat so our system will calculate the price and profit for each of them. After calculating if the system finds that cultivating potatoes is more profitable despite less number of production of wheat, it will suggest potatoes to cultivate. To make the system easily accessible to all the farmers around the country we have planned to develop software, mobile applications and website. Also when a farmer logins in our system, his land information can

be automatically collected with the help of Global Positioning System (GPS) [18]. As a result, farmer needs not to put any information into system, this will make the farmers comfortable as most of them lack the knowledge of using technology. We are also planning to make a Video Manual for farmers so that they can learn how to use the system properly and get to know about all the instructions.

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