Autonomous Winter Wheat Variety Selection System

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***Abstract*—Public and private organizations have been investing significant financial and human resources to develop crop varieties suitable for different commercial destinations, regional characteristics and agronomic factors. The high number of variables and consequent complex analysis are factors that make the task of selecting a specific crop variety, that best fulfill the particularities of a given farm, a challenging one. In this scenario, this work proposes a ranking/decision method to deal with the stochastic problem of select a winter wheat variety, taking into account the random factors that influence in the specific decision. The system evaluates the commercial destination, site-specific and agronomic importance of varieties treats, such as resistance to diseases and lodging, to output a list of best winter wheat varieties choices, for a particular situation. The system's accuracy has been verified by experts of crop science, where a number of random outcomes were tested against specialist opinion.**

***Index Terms*—variety selection, winter wheat, autonomous system, agricultural system, decision support system, seed selection**

I. Introduction

Decision Support Systems (DSS) are computer technology solutions that can be used to support complex decision making and problem solving [1]. In the agriculture field, the last years have brought important works at different sectors and cultivations. The work of [2] has designed and applied a fuzzy decision support system, concerning site specific nitrogen fertilization. Moreover, [3] proposed a new decision support system, for sustainable management of vineyards. Also, [4] proposed a DSS to for rainfed agricultural areas in Mexico. A crop model is used to compute yield giving parameters of rainfall occurrence and soil water depletion by evapotranspiration.

In the crop variety selection context, the high number of options and the many factors that have to be taken into account, turn the selection of a crop variety, a complex and timely task. Varieties are frequently compared in a single factor analysis, in other words, results for an agronomic characteristic are plotted in a way to identify the better variety options. While these results represent a valuable source of information, the final decision requires a multi-factor analyses which takes different agronomic and site-specific characteristics onto the decision making.

Decision support tools and expert systems have been applied to advanced agriculture markets using different methods. The work of [5] had organized electronically and designed an expert system to select wheat varieties in India. The system was developed using Active Server Pages in a client/server model. The model proposed uses a knowledge based molded by rules that take factors such as location, sowing condition, yield, protein content, response to diseases and insects into account, to suggest a variety of choice based on "*IF/THEN"* rules. In contrast, [6] projected a knowledge model for design of target yield under different temporal and special environments taking into account the integration of effects of yield potential of photosynthesis and temperature, average yield level of last three years, soil fertility, fertilization and water management level and production technology level on yield increment.

Moreover, [7] proposed a Decision Support System to support Danish farmers to select a winter wheat variety, based mainly on the expected net revenue against the expected costs of production. The method takes future uncertain observations into account. The decision process is designed using the stochastic programming model, which consists of calculating for each variety the expected net revenue, that subtracts costs of diseases treatments and fertilizers input. Foregoing work by [8], [9] first shown the web-based information system "*SortInfo*", which undertake data from several sources of Danish varieties field trials. Final users can rank varieties of different crops accordingly to determined properties, or select a given number of varieties sorted best or worst for a specific characteristic.

In addition, [10] developed a gross margin model to select varieties of winter wheat, winter barley and spring barley. The model evaluates the monetary terms and takes account of the variable costs of production. The

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deterministic model allows the selection of target diseases and the input of prices for individual varieties to deliver a gross output of profit taking returns and costs.

Furthermore, [11] investigated the use of a quantitative portfolio to improve wheat variety selection incorporating yield variance and covariance between resulted yields to boost yield and minimize risks. The study concluded that variety portfolios can enhance profits and lower risk fort wheat producers in Kansas apart the selection of a single variety. A similar approach [12] applied portfolio theory in order to select rice varieties to maximize profit and minimize risks for Arkansas' farmers. Results suggested that portfolio sowing of rice varieties could had increased profits from 3 to 26%.

In places with limited access to technology, participatory variety selection of crops was adopted in order to select the best ones suited to local characteristics and accepted by farmers [13]. Researches have study, identify and disseminate varieties with better yields and strong resistance to climatic and diseases factors [14], [15].

This work proposes a decision support system for winter wheat variety selection which takes into perspective local specific characteristics and multi agronomical factors to generate a list of appropriate varieties to a given scenario. A ranking/decision method is proposed to deal with the stochastic problem. The system provides graphical user interfaces in order to identify the site-specific and the agronomic factors, as for display the list of best wheat varieties candidates.

II. Materials and Methods

The data for the winter wheat variety selection tool format is presented, followed by the explanation of the system architecture and the detailed description of the ranking process to select the best wheat varieties applying a multi-factor analysis.

A. *Database Layout*

With the intent of helping farmers to select appropriate varieties of winter wheat, the AHDB-UK has deployed an online selection tool. This tool can be used to compare selected varieties trials results for the sake of a given characteristic. Also, agronomic factors of varieties, such as resistance to diseases and lodging, may be selected and displayed.

By the *"view data"* option of the table display, the results of all analysis have been exported individually, to later, generate the database of the current work. Fig. 1 displays the data classes exported and their series of values.

The described variety selection tool does not have the functionality to perform a multi-characteristic analysis to generate a list of best choices. The farmer is required to execute multiple individual analysis given his scenario and then summary information and compare the results. Given the number of different varieties, site-specific and agronomic factors, this task may require a long time and considerable effort, and is easily susceptible to mistakes. The system proposed in this work, has the objective of taking the valuable data gathered by the AHDB tool and deploy it in conjunction with an alternative approach that takes into account multiple factors and generates a list of best options of varieties, for a given scenario. In this way, eliminating the need of multiple individual analysis and lowering the risk of human error in the variety selection process. A stochastic model, by means of a ranking method to generate a number of best varieties, given a random multi-factor analysis situation, is proposed to address the problem.

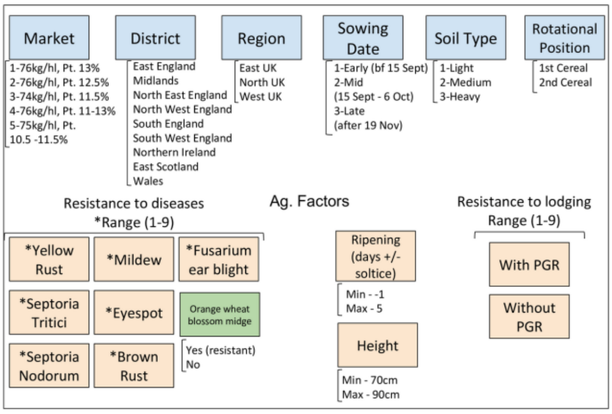

Figure 1. Varieties data layout showing the different system's classes and range of possible values.

B. *System Architecture*

This subsection describes the system's overview, which has been developed with the high-level technical computing language and interactive environment *"Matlab"* [16].

Fig. 2 presents the system's data flow diagram. In the first GUI (Graphical User Interface) the user is required to identify the scenario as means of "*Market"*, "*Sowing Date*", "*Soil*", "*Rotational* Position", "*District*" and "*Region*". Fig. 3 shows an example of user input to this first interface. Given the scenario, the specific matching data is read according to that specific situation. For example, the data analysis of the "*Market = Group 1*", "*Sowing = Mid*", "*Soil = Heavy*", "*District = North West England*" and "*Region = North UK*". This data analysis takes five different files, exported in the AHDB tool, besides the variety versus market table. After the loading, the data is analyzed by means of a ranking process, where varieties with better trial results in the specified characteristics are identified with a higher number of votes. This process is denoted by the "*rank scenario*" node. The first phase of the selection that uses the site-specific characteristics has also an exclusive implication. In order to limit the number of varieties to be taken into account for the next ranking phase, a number *n* of wheat varieties that have the highest number of votes (better results) are kept, while the others are discarded of the selection. This screen has also a menu item to access the system's parameters, where the user can increase or decrease the weight of a given factor.

In the next step of the process the user selects the agronomic factors, in the second GUI. In this screen, the user is required to identify the level of importance to resistance to diseases, number of ripening days and height ranges. This interface is depicted in the Fig. 4. As the agronomic factors are distinguished, the final step of the ranking process is concluded where the *n* previous varieties selected have votes appended to their previous sum, accordingly to the matching to the user's requirements for the agronomical factors mentioned previously. The results of votes are summed and normalized, as shown by the "*compute best varieties*" node in the graph. Lastly, as the final step of the process flow, the third GUI shows the selected varieties with the best scores in a list and graphical way, as is shown by Fig. 5.

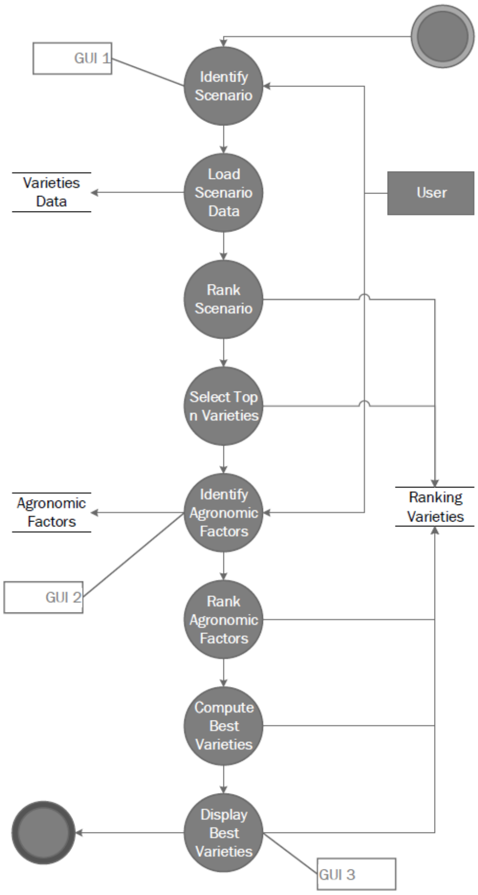

Figure 2. Data flow diagram expressing the different steps on the process of variety selection.

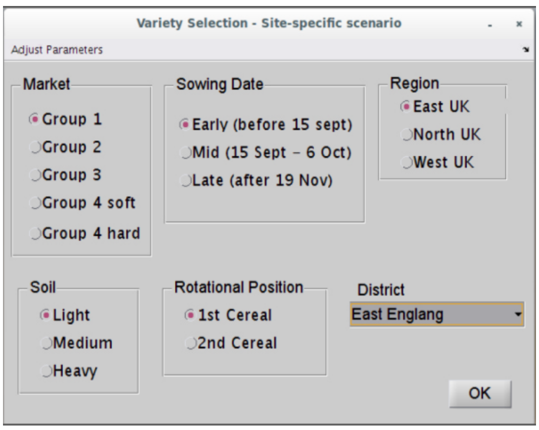

Figure 3. First graphical user interface to identify the site-specific factors.

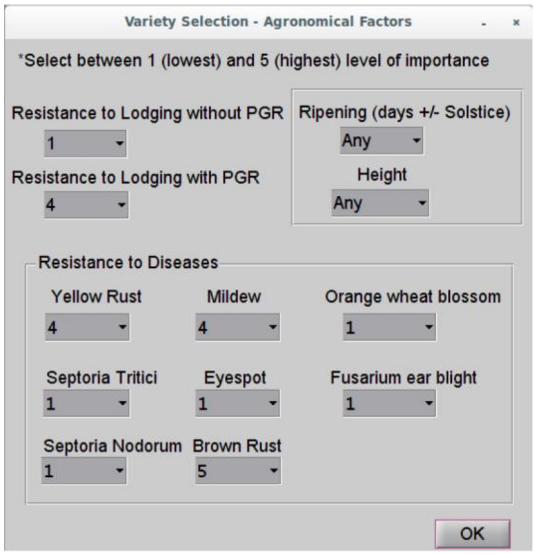

Figure 4. Second graphical user interface where the importance of agronomical factors is selected.

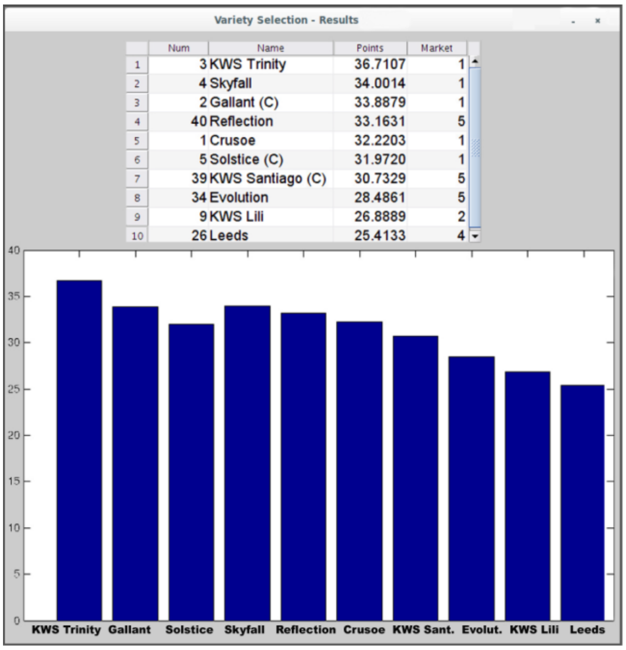

Figure 5. The third graphical user interface showing the rank of varieties for a specific situation.

C. *Ranking/Decision Strategy*

In order to deal with the stochastic problem of having a high number of agronomical and site-specific characteristics combinations, in the selection of a variety of winter wheat, a ranking/decision strategy that appends votes for varieties in relation to results of trials and agronomical treats compared to a random user's preferences is proposed. Considering that the identification of site-specific and agronomical factors has been already explained previously, this section focuses only in detailing the ranking process. Fig. 6 brings an UML [17] activity diagram of the ranking process.

1) Ranking of site-specific factors: When a farmer decides to cultivate winter wheat, one of the main factors regarding the variety selection, is choose a target market.

Wheat varieties are mainly grouped in this way. Therefore, it is appropriate to omit varieties that are not part of the selected market group.

The first part of the ranking process, shown as "*ranking market*" in the Fig. 6, performs this logic by appending a *hit* value parameter for the matching varieties and a negative *miss* value parameter to all other varieties. In this way, the selection focus on the varieties of the desired market while making extremely difficult to a variety that is not part of the selected market to be listed in the final result.

Aside the special ranking for the market destination, the ranking of other site-specific parameters is based mainly in the trials results contained in the database. The AHDB has summarized the results of trials by the following variables:

- *Yield:* Number that shows the performance of a given winter wheat variety in *t/ha*.
- *Number of trials:* The number of experiments that have been performed to a specific analysis factor and variety.
- *% Yield:* Percentage yield of the control. A range of established varieties are selected as controls and the average UK yield of these varieties is set to *100%*. For example, if the average yield of the control varieties is *10.2t/ha*, a variety that yields *10.4t/ha* will be shown as *102%*.

In the "*Rankin* other *site factors"* stage, the site-specific factors of "*Soil Type"*, "*Sowing Date"*, "*Rotational Position*", "*District*" and "*Region*" are computed individually. Every one of them have specific results for a given situation. For example, the results of "*Soil Type = Light*" may be different from "*Soil Type = Heavy*" for the same wheat variety. Every factor, is addressed separately, also having different values of weight parameters. In this context, the site-specific factors ranking, occurs as following:

- Append to the variety the number of votes equals to the yield result multiplied by the weight parameter for yield.
- If the number of trials is above a determined *threshold*, append to the variety the number of votes equal to the "*trials hit*" parameter.
- If the variety is on the top "*n*" "*%Yields*", append to the variety the number of votes equal to the "*top % yield parameter*".

This ranking approach allows the evaluation of the different aspects of the results, performing a broad evaluation of the varieties by attributing votes to important features, accordingly to pre-specified weights and hit matching parameters.

2) Ranking of agronomic factors: In another way from site-specific characteristics, the agronomic factors do not change in different trials or locations characteristics, they are genetic traits of a wheat variety. Therefore, in order to perform the ranking, the selected varieties in the previous step are read in a loop, and the agronomic factors are loaded for each one of them to compute the final ranking in the following fashion:

Resistance to diseases ("*yellow rust*", "*septoria tritici*", "*septoria nodorum*", "*mildew"*, "*eyespot*", "*brown rust*" and "*fusarium ear blight*") are represented in the agronomical factors data as variables ranging from *1* (minimum) to *9* (maximum resistance). The votes are computed as the following:

- Append to the variety the number of votes equals to the variety resistance to a given disease times the weight of resistance importance selected by the user to it.

Distinctively from the others, the resistance to orange wheat blossom midge disease is not represented in a range of resistance, but in a binary denotation (yes or no). The vote is computed in the following:

- If the user requests resistance to orange wheat blossom midge, attribute to the variety the value equals to the weight selected by the user multiplied by *9* (maximum resistance of variety for a common disease), in case the variety has the resistance to it; or multiply by *0*, if the variety does not have the resistance to it.

Height and ripening days: The height and ripening days ranking occurs every time the user selects a value different of *"any"*. The value of the variety is then compared to the height or ripening days selected by the user in a set of ranges, as follows:

- If the height of the variety is between the range specified by the user, append to the variety the number of votes equals to the "*height hit*" parameter.
- If the range of the variety is between the range specified by the user, append to the variety the number of votes equal to the "*ripening days hit*" parameter.

Lodging: The lodging ranking with and without the use of PGR (Plant Grow Regulator) is performed in a similar way to the disease resistance. The varieties have a certain resistance to lodging ranging from *1* to *9*. The user has the option to select the weight of importance of the lodging parameters that govern the ranking as follows:

- Append to the variety the number of votes equals to the variety resistance to lodging times the weight of resistance importance selected by the user to it.

At the end of the process, after the computation of all varieties votes for the agronomical factors, a multi-criteria decision analysis is performed. Taking the normalize sum of votes multiplied by the weight of each conjunct of factors, the final ranking of best wheat varieties candidates is generated. The results are then displayed in a graphical way to the user, as depicted in the Fig. 5. The final result of the ranking process is summarized by (1).

$$Rank_{var} = \left(\sum_{i=1}^{n} varS_i \times W_{ssf} + \sum_{j=1}^{k} varAg_j \times W_{agf}\right) \times normC \quad (1)$$

where $Rank_{var}$ is the final rank/decision score for a wheat variety; *var* represent the site-specific factors of the first phase of the ranking; W_{ssf} is the weight of site-specific factors in the vote sum; *varAg* are the agronomical factors of the second phase of the ranking process; W_{agf} is the weight of agronomical factors in the vote sum; and *normC* is the normalization constant.

This work proposes a decision support system for winter wheat variety selection which takes into perspective local specific characteristics and multi agronomical factors to generate a list of appropriate varieties to a given scenario. A ranking/decision method is proposed to deal with the stochastic problem. The system provides graphical user interfaces in order to identify the site-specific and the agronomic factors, as for display the list of best wheat varieties candidates.

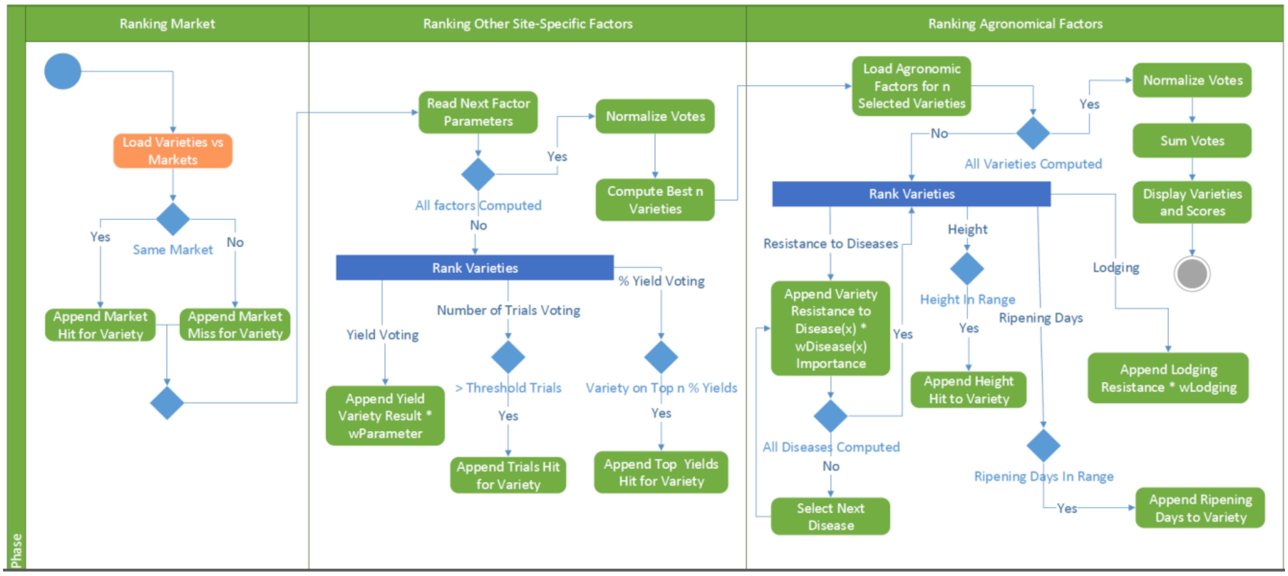

Figure 6. Activity diagram showing the different phases of the ranking process where varieties votes are computed accordingly to site-specific and importance of agronomical traits selected by the user.

TABLE I. Random Results Extracted from the Proposed Experiment. Columns 1 to 5 Refer to Site-Specific Factors (Market, Soil Type, Data Sown and District), for More Details Consult Fig. 1. Columns 6 to 17 Refer to Agronomical Factors Where the Minimum Weight of Importance Is Equal to 1 and Maximum is Equal to 5. The Last Two Columns Show the Selected Variety and Its Score

Mar.	S. Type	D. Sown	Rot. Pos.	District	Lod. No PGR	Lod. PGR	Y.R.	Sept. T.	Sept. N.	Or. W. B.M.	Mil.	Fus. E. B.	Eyes.	B.R.	R.D.	Ht.	Variety	Score
1	1	2	1	E. Eng.	1	4	4	4	5	5	4	3	5	3	1	1	Gallant	82.88
1	1	2	1	E. Eng.	1	4	4	4	5	5	4	3	5	3	1	1	Skyfall	75
3	3	1	2	NW. Eng.	5	2	1	4	5	5	2	1	3	2	1	1	Delphi	77.98
3	3	1	2	NW. Eng.	5	2	1	4	5	5	2	1	3	2	1	1	Scout	76.71
4	2	2	2	SW. Eng	4	3	3	5	1	4	2	1	2	4	4	4	Cougar	100
4	2	2	2	SW. Eng	4	3	3	5	1	4	2	1	2	4	4	4	Leeds	82.48
2	2	1	1	Midlands	5	2	5	5	1	2	1	5	4	2	3	3	KWS Lili	81.79
2	2	1	1	Midlands	5	2	5	5	1	2	1	5	4	2	3	3	KWS Santiago	61.83
2	1	3	2	N. Ireland	2	5	3	2	2	3	5	1	1	1	4	1	KWS Lili	85.55
2	1	3	2	N. Ireland	2	5	3	2	2	3	5	1	1	1	4	1	Panorama	57.7
5	3	2	1	E. Scot.	3	1	4	4	4	5	5	1	1	1	4	5	Conqueror	75.85
5	3	2	1	E. Scot.	3	1	4	4	4	5	5	1	1	1	4	5	KWS Kielder	75.38
1	1	1	2	E. Scot.	2	1	4	2	2	5	2	1	1	2	5	3	Skyfall	100
1	1	1	2	E. Scot.	2	1	4	2	2	5	2	1	1	2	5	3	KWS Kielder	81.87
3	1	3	1	N. Ireland	4	5	3	4	3	5	4	4	3	1	3	5	KWS Croft	76.95
3	1	3	1	N. Ireland	4	5	3	4	3	5	4	4	3	1	3	5	Monterey	75.93
4	3	3	2	NE. Eng.	5	2	2	5	5	2	1	1	4	2	5	1	Myriad	70.63
4	3	3	2	NE. Eng.	5	2	2	5	5	2	1	1	4	2	5	1	Alchemy	66.43
5	2	2	1	NE. Eng.	4	2	4	3	3	1	5	3	1	3	1	1	Reflection	73.34
5	2	2	1	NE. Eng.	4	2	4	3	3	1	5	3	1	3	1	1	JB Diego	52.34
1	1	1	1	S. Eng.	2	4	3	1	1	4	3	1	2	4	1	4	Reflection	82.97
1	1	1	1	S. Eng.	2	4	3	1	1	4	3	1	2	4	1	4	Skyfall	75.89
4	3	3	2	Wales	5	4	3	5	1	1	5	3	2	3	5	4	Cougar	73.99
4	3	3	2	Wales	5	4	3	5	1	1	5	3	2	3	5	4	Revelation	70.93
2	2	1	2	E. Eng.	1	5	1	5	3	1	4	4	1	1	4	2	KWS Lili	93.37
2	2	1	2	E. Eng.	1	5	1	5	3	1	4	4	1	1	4	2	KWS Santiago	76.27
3	2	2	1	Midlands	3	5	4	5	2	1	3	5	5	5	1	1	Delphi	87.89
3	2	2	1	Midlands	3	5	4	5	2	1	3	5	5	5	1	1	Invicta	65.29
5	2	2	1	N. Ireland	5	2	2	5	4	3	2	2	4	3	3	1	KWS Santiago	62.81
5	2	2	1	N. Ireland	5	2	2	5	4	3	2	2	4	3	3	1	Reflection	55.25

III. RESULTS

Fig. 5 shows an output example of the system, where the graphical interface presents the best varieties list accordingly to the user's input data. The varieties are shown in a list containing its system index, name, points (rank score) and market. Also the varieties are pictured in a graphical way, in view of their resulting votes.

In accordance to the ranking/decision process, presented previously, varieties of different markets of destination are omitted, while the ones of the same market of the user selection are emphasized. However, in case a variety of a different market has a strong correlation with the other factors, it still can be displayed in the final list, signaling a high potential candidate, if a different market is taken into account.

In order to test the system's feasibility, an experiment was proposed. The multi-factor input parameters Markets (*5*), Sowing Date (*3*), Soil Type (*3*), Rotational Position (*2*), District (*9*), Resistance to diseases (5^8), Resistance to lodging (5^2), Ripening Days (5) and Height (5) generates a total of *197.753.906.250* of different input combination possibilities. A simulation has been proposed to generate some of the possible combinations and evaluate the system accuracy.

The algorithm selects the best two wheat varieties for each iteration. All the site-specific factors are generated for each time iteration (*810* combinations per time). The agronomical factors are generated with random weights for each iteration of the algorithm. In the stated experiment, the parameter *time* was set to *5*. In this way, a total of *4050* different combinations have been tested. Two varieties have been selected in each combination, generating a total of *8100* results. The results comprise all the possible combinations of site-specific factors, and partially, the possible agronomical factors combinations, using random weights in each iteration.

Table I presents the selected experiment outcomes. The rows of the columns show the selected varieties for a random scenario. Each time, the two best varieties are presented. A list of *30* random results, out of the *8100*, have been selected to be evaluated by an expert in the subject of winter wheat, in order to qualify the system's accuracy. After a cautious analysis, the results showed the feasibility of the system, where all the *30* selections were considered appropriated and maximized to the selected input characteristics of site-specific and agronomic factors.

IV. CONCLUSION

Variety selection is one of the most important decisions to be made by farmers early in the season when planning to cultivate a given crop. Research agencies results of field trials are considered a valuable guideline resource in aid of this task. In general, this data is distributed in a printed media or in limited analysis platforms, which difficult the use and analysis by farmers, taken into account the high number of variables that must be considered in the crop variety selection process.

This work proposed a solution to address the stochastic problem of selecting a variety of winter wheat, considering the multi-factors related to site-specific and agronomical characteristic, by means of a ranking/decision strategy. The results have been evaluated by experts, where the accuracy of the outcomes have been confirmed in all the tested situations. As future work, it is planned the generation of a larger database of results, using different input factors combinations to be deployed with machine learning and data mining algorithms, such as decision trees for autonomous classification tasks.

APPENDIX A DEFAULT PARAMETERS

Parameter	Default Value
Hit market	15
Miss market	-15
Hit threshold trials	10
Weight of site-specific factors	0.5
Weight of agronomical factors	0.5
Number of displayed varieties	10
Yield Weights per factor	
Data sowing	3
Soil type	4
Rotational positional	3
District	2
Region	2

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