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(54) **METHOD AND SYSTEM FOR USE OF
ENVIRONMENTAL CLASSIFICATION IN
PRECISION FARMING**

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(75) Inventors: **DONALD P. AVEY**, Ankeny, IA (US);
PHILLIP L. BAX, Johnston, IA (US);
RICHARD GLENN BROOKE,
Johnston, IA (US); **DAVID S. ERTL**,
Waukee, IA (US); **JOSEPH K.**
GOGERTY, Algona, IA (US); **DAVID**
J. HARWOOD, Johnston, IA (US);
MICHAEL J. LAUER, Des Moines,
IA (US); **TERRY EuCLAIRE**
MEYER, Urbandale, IA (US); **TODD**
A. PETERSON, Johnston, IA (US)

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(57) **ABSTRACT**

Correspondence Address:
MCKEE, VOORHEES & SEASE, P.L.C.
ATTN: PIONEER HI-BRED
801 GRAND AVENUE, SUITE 3200
DES MOINES, IA 50309-2721 (US)

Methods and software for selecting seed products or other agricultural inputs for planting within an associated land base include dividing the field into regions, providing an environmental profile for each of regions, determining a recommendation of a seed product to plant within each of the regions based on the environmental profile and performance of the genotype of each of the seed products in the environmental profile of the regions, and providing an output identifying the seed product to plant within each of the regions.

(73) Assignee: **PIONEER HI-BRED INTERNA-
TIONAL, INC.**, Johnston, IA (US)

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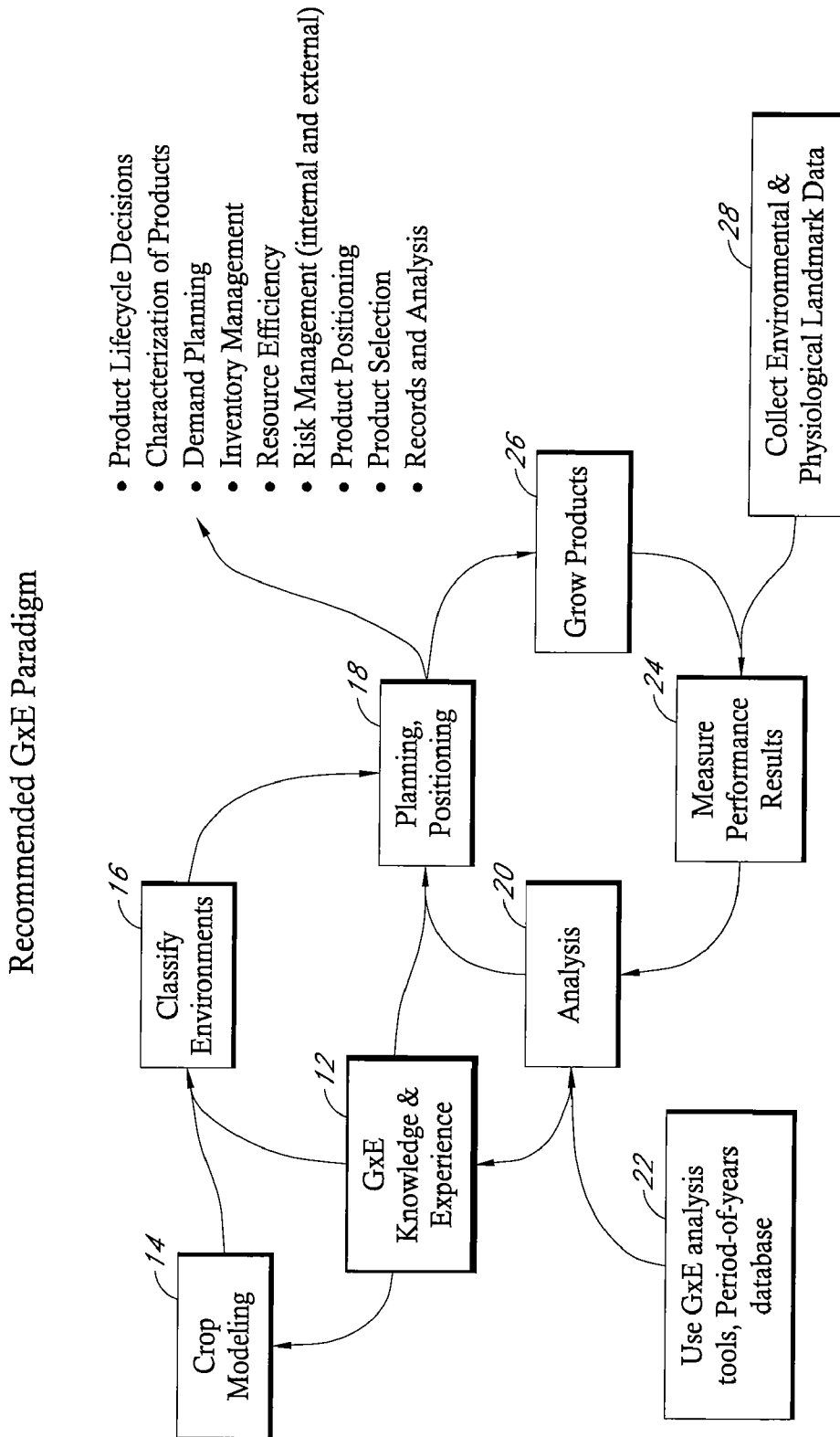


FIG. 1

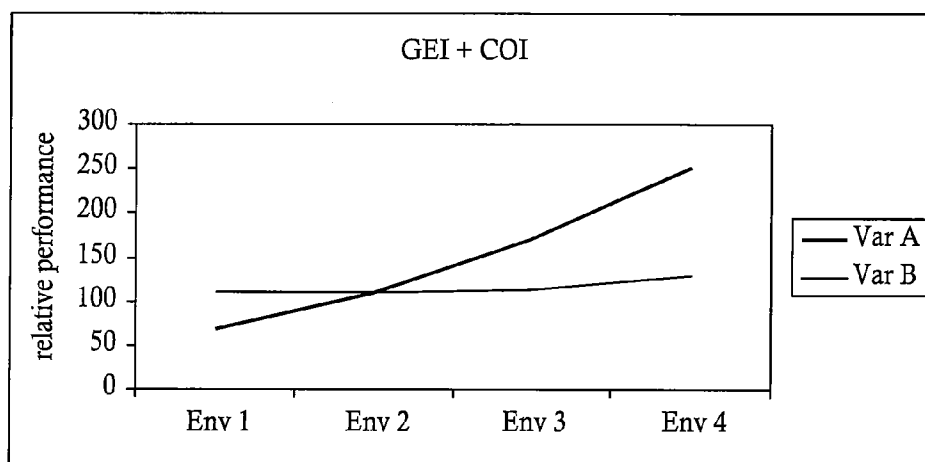


FIG. 2A

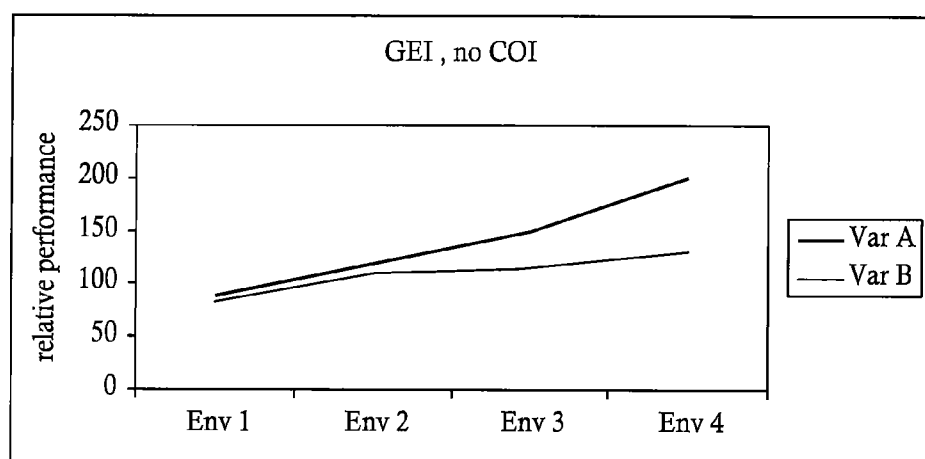


FIG. 2B

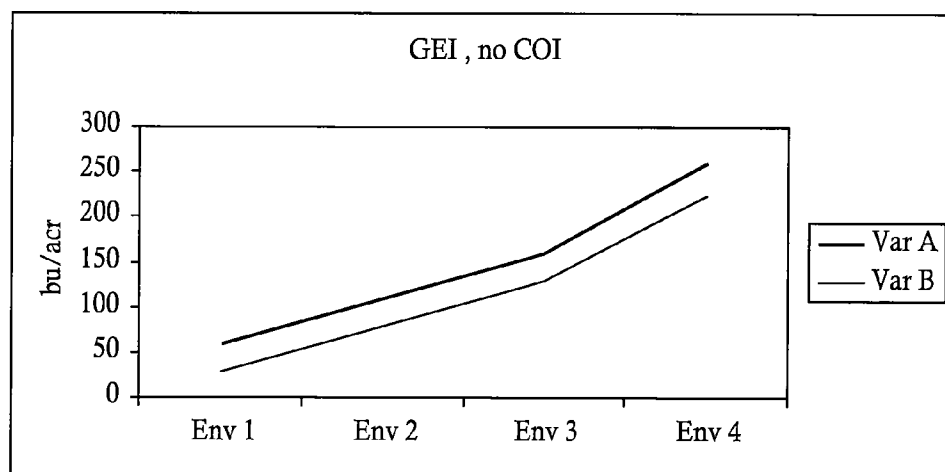


FIG. 2C

Environment-standardized GGE biplot of grain yield of 18 maize hybrids (H1-H18) grown in 266 environments over three years, stratified by state

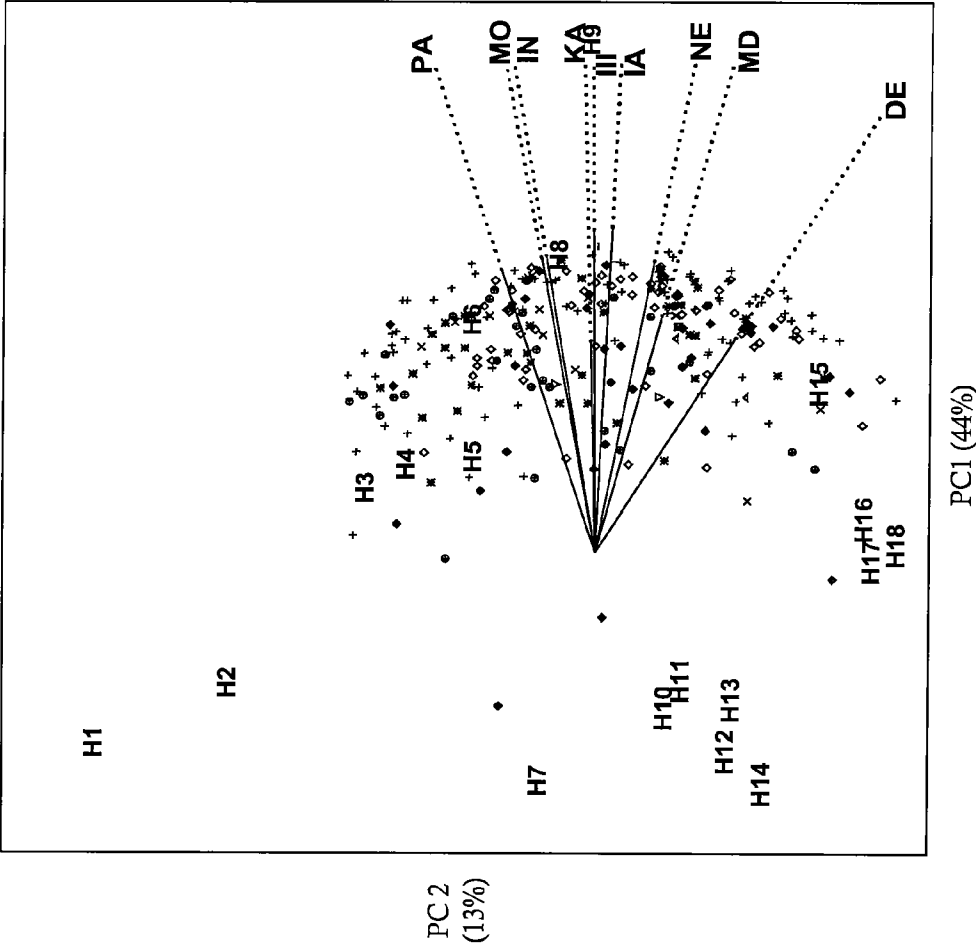


FIG. 3

Environment-standardized GGE biplot of grain yield of 18 maize hybrids (H1 - H18) grown in 266 environments over three years, stratified by environment class

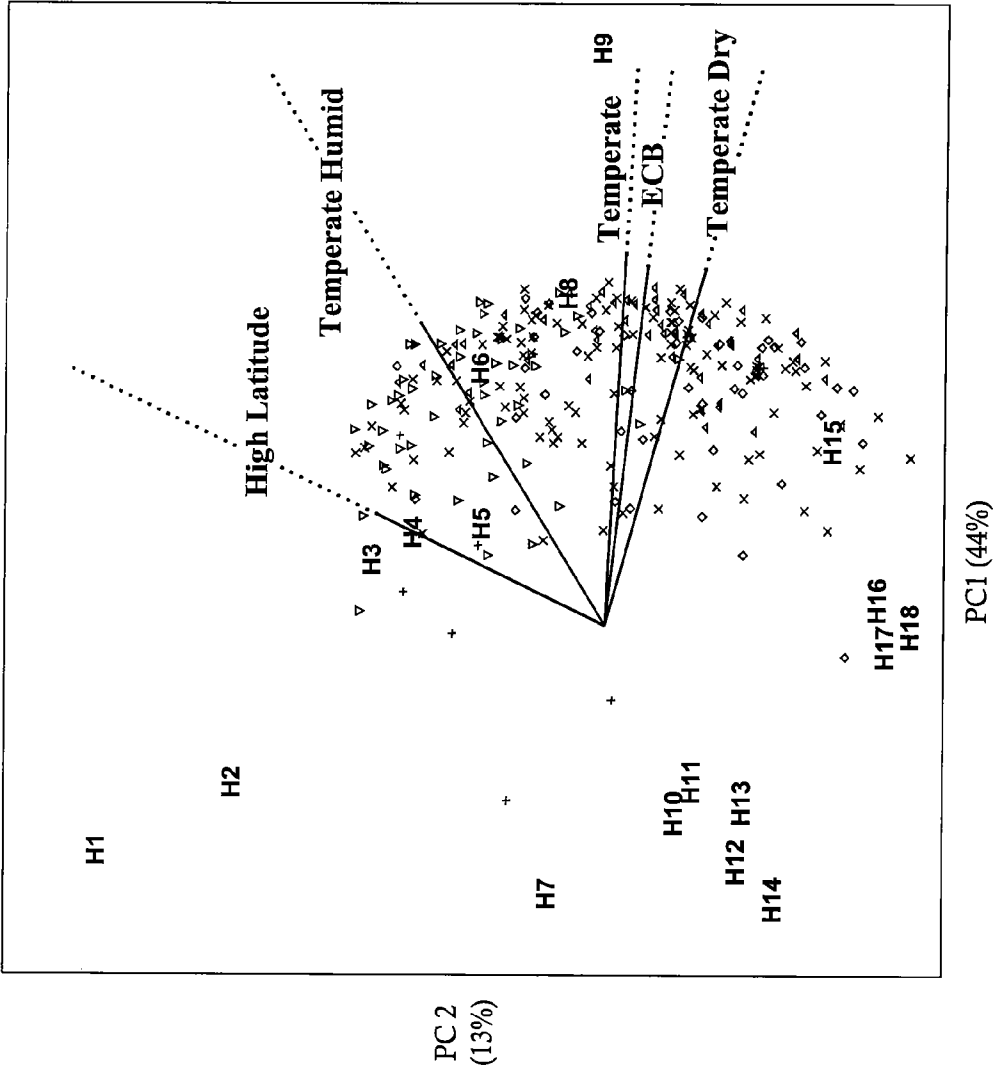


FIG. 4

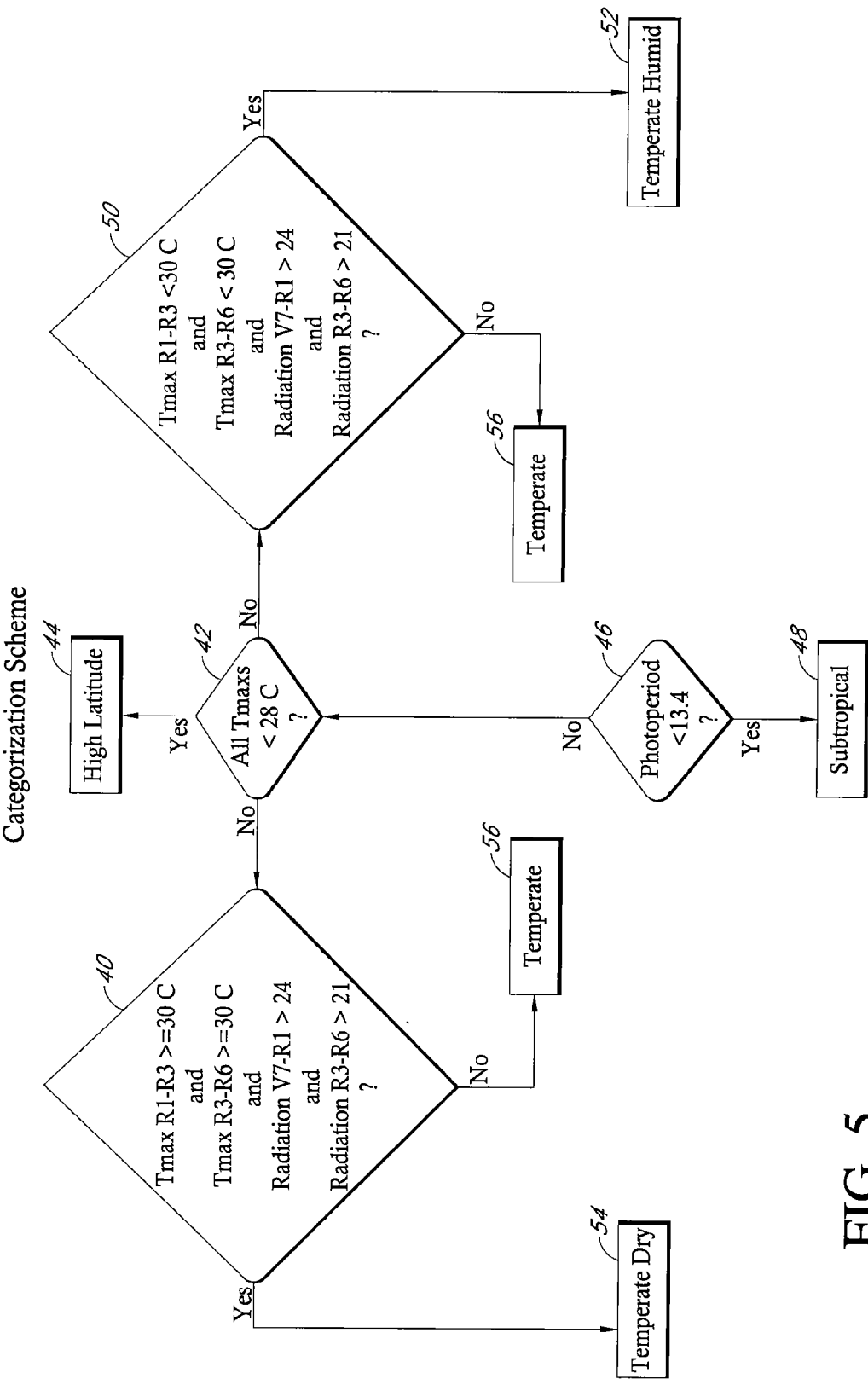


FIG. 5

Environment Class Frequency
CRM 103

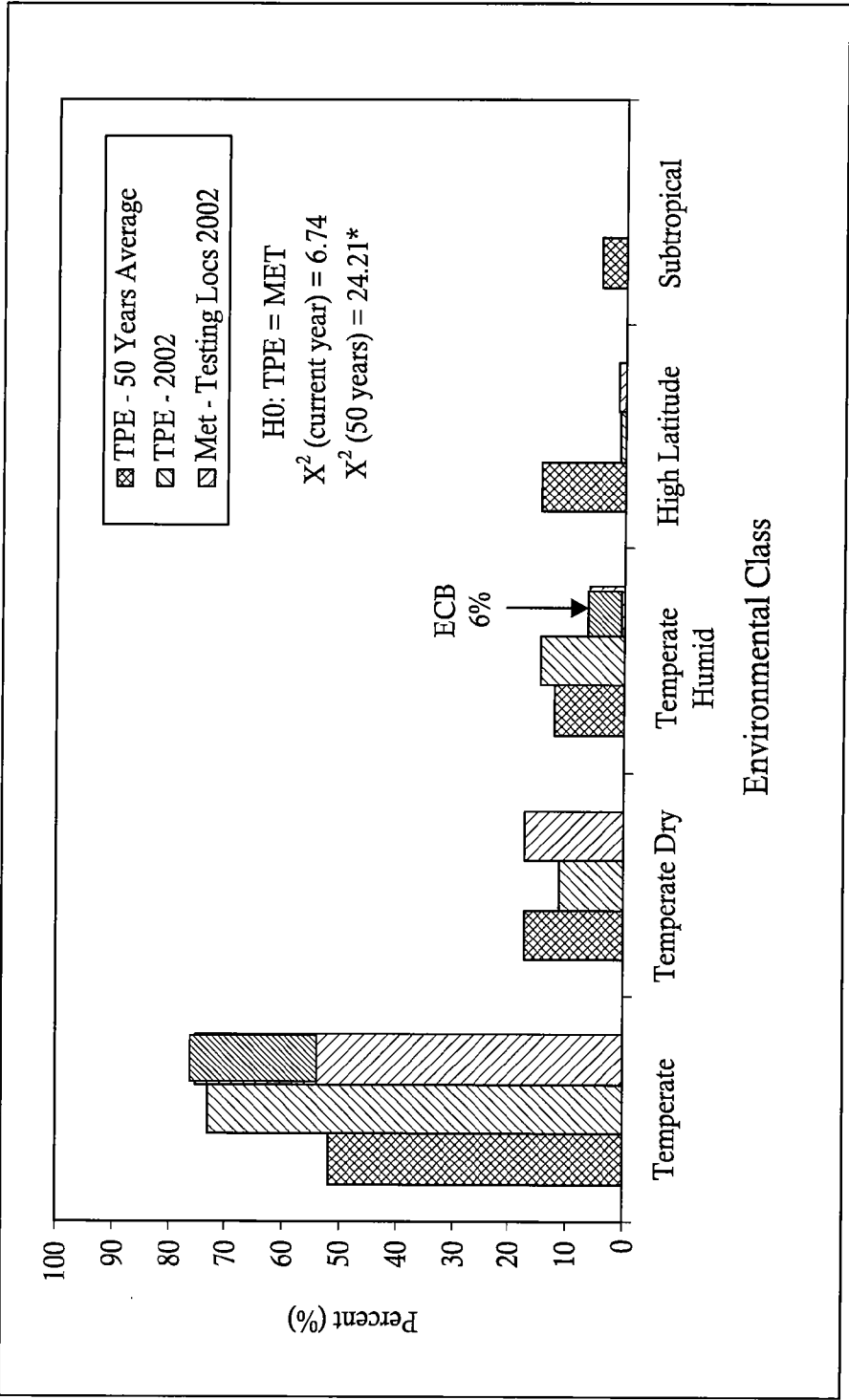
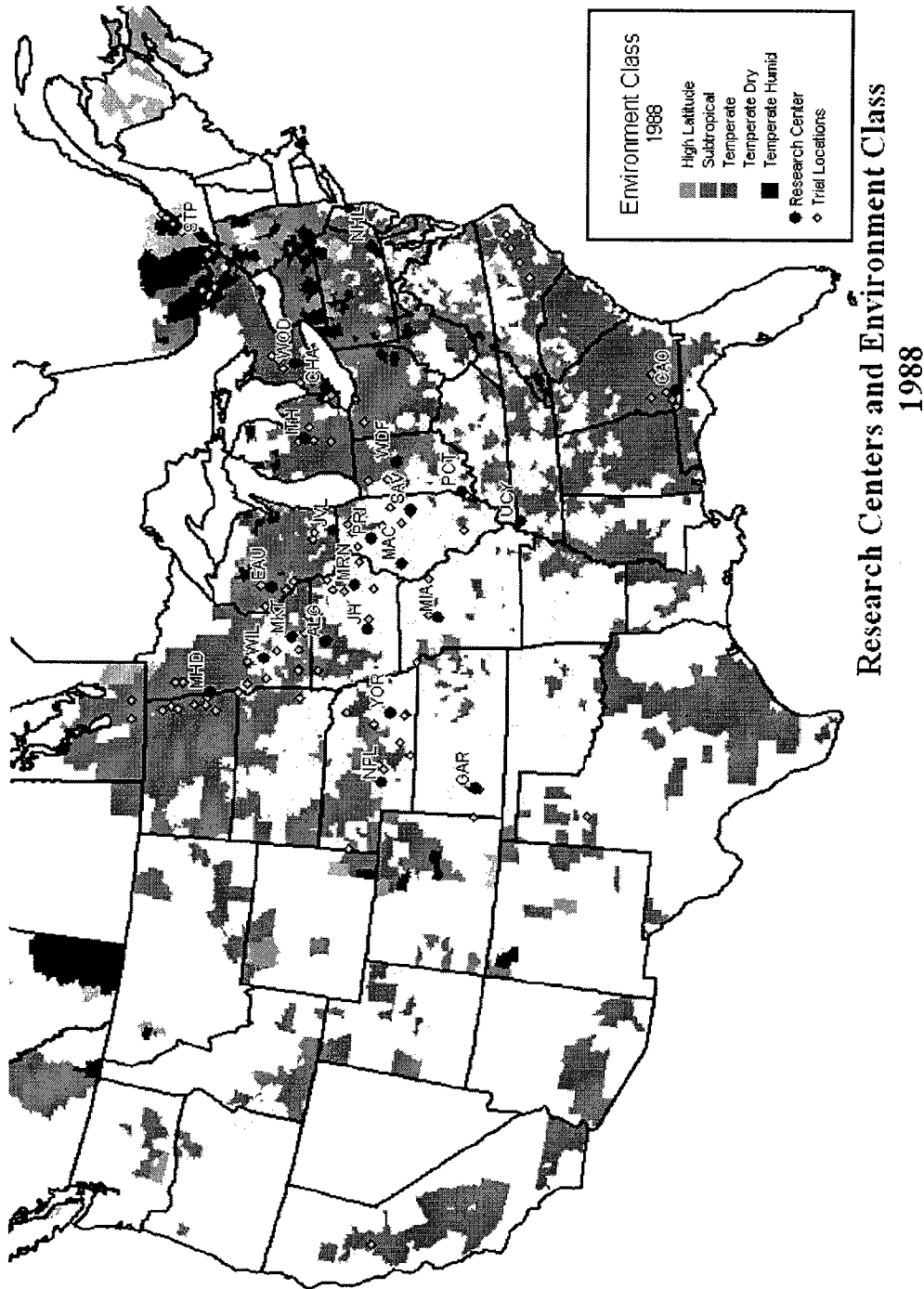


FIG. 6



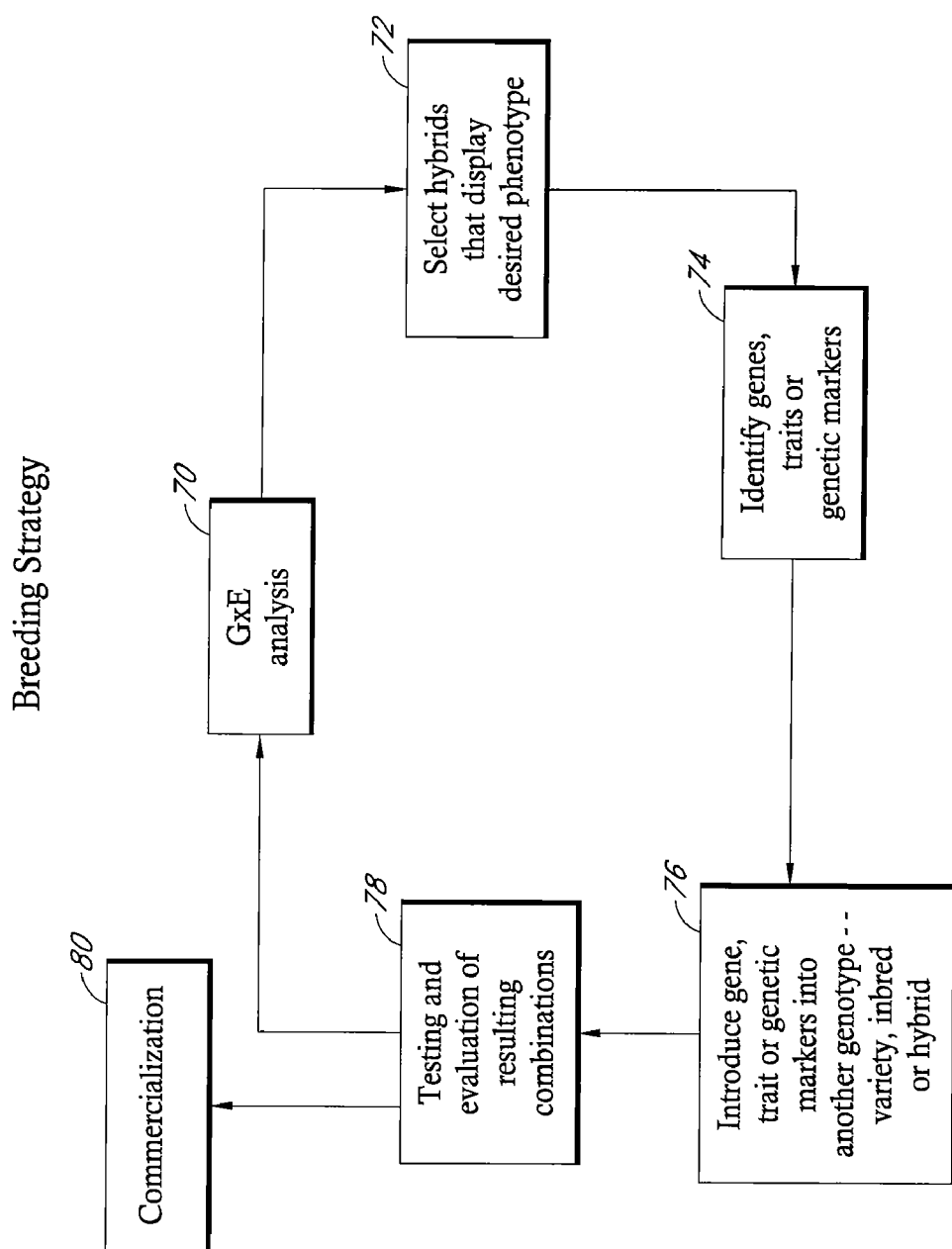


FIG. 8

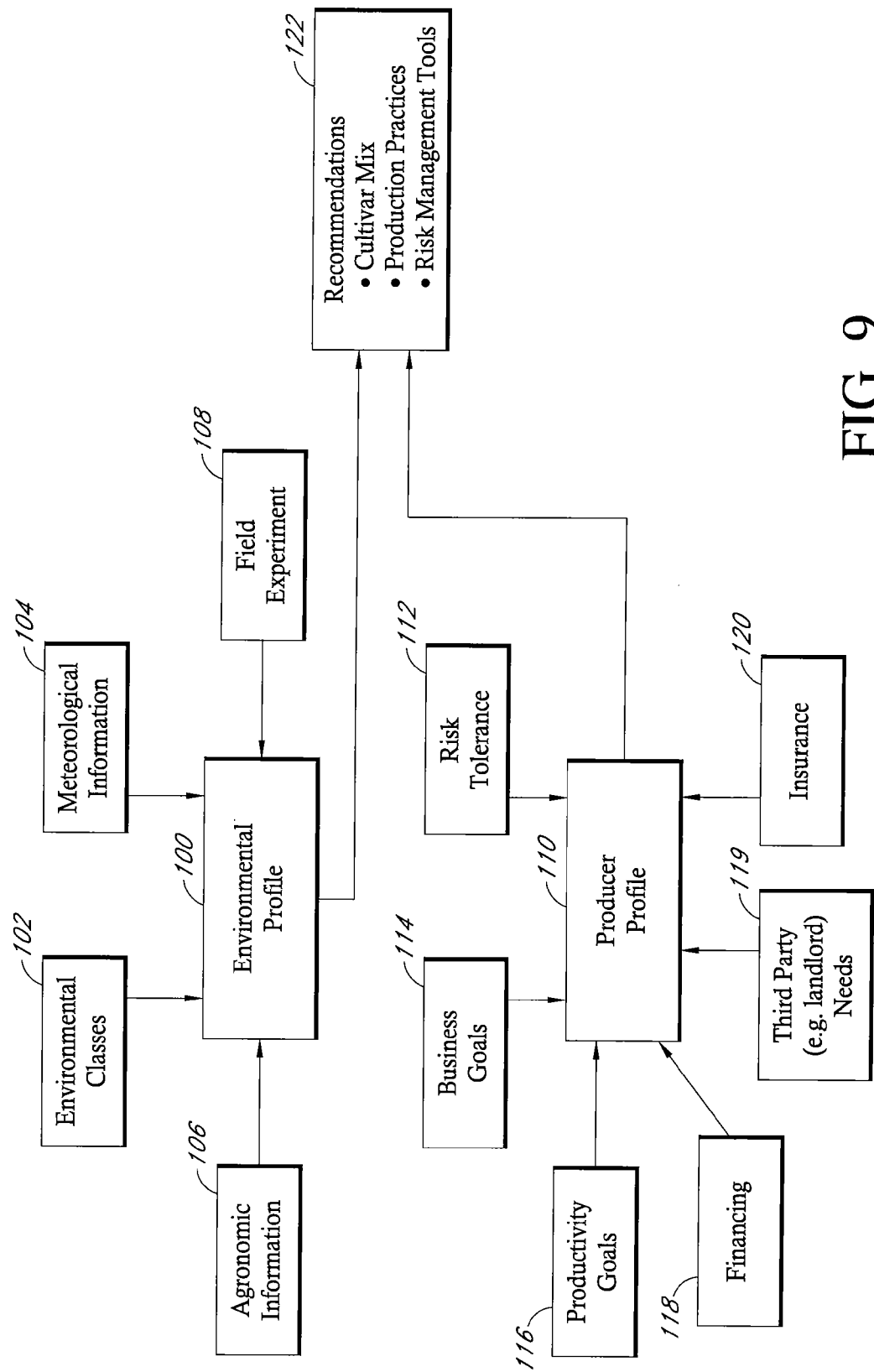


FIG. 9

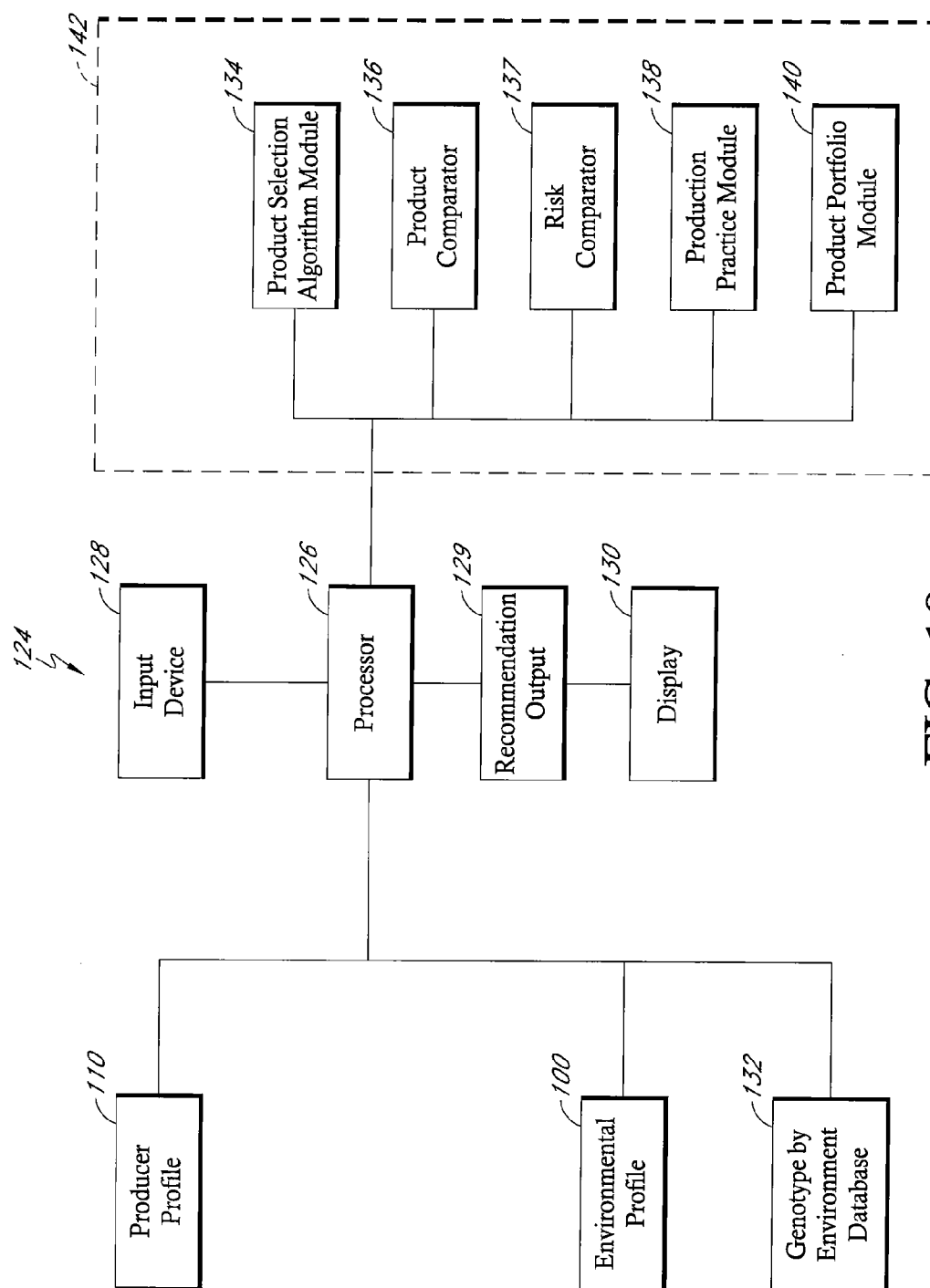


FIG. 10

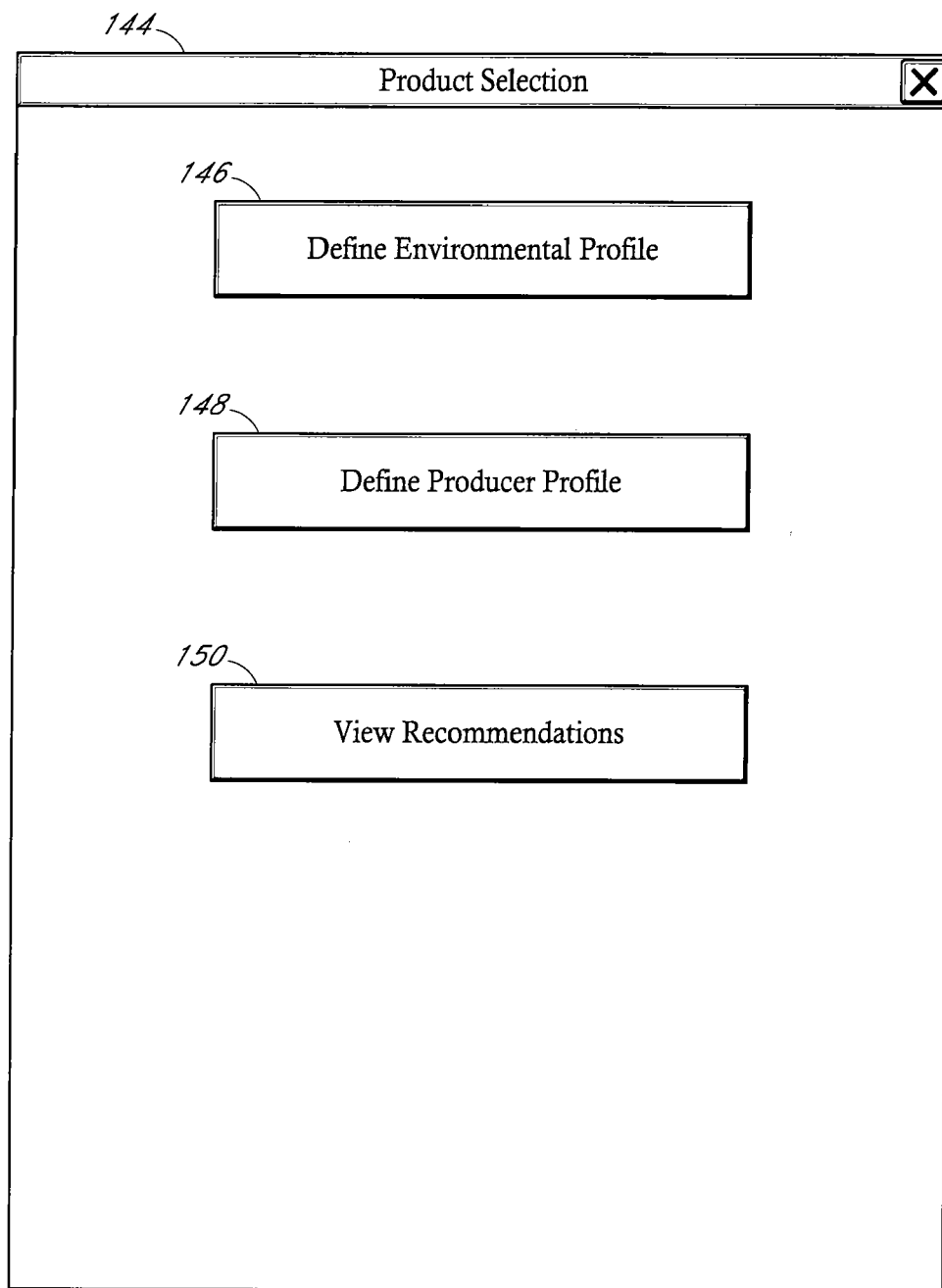


FIG. 11

152

Recommendations			
154 Product	156 Acres	157 Risk Assessment	158 Crop Revenue Assurance
Hybrid1	Acres1	X prob	\$1
Hybrid2	Acres2	Y prob	\$2
Hybrid3	Acres3	Z prob	\$3

FIG. 12

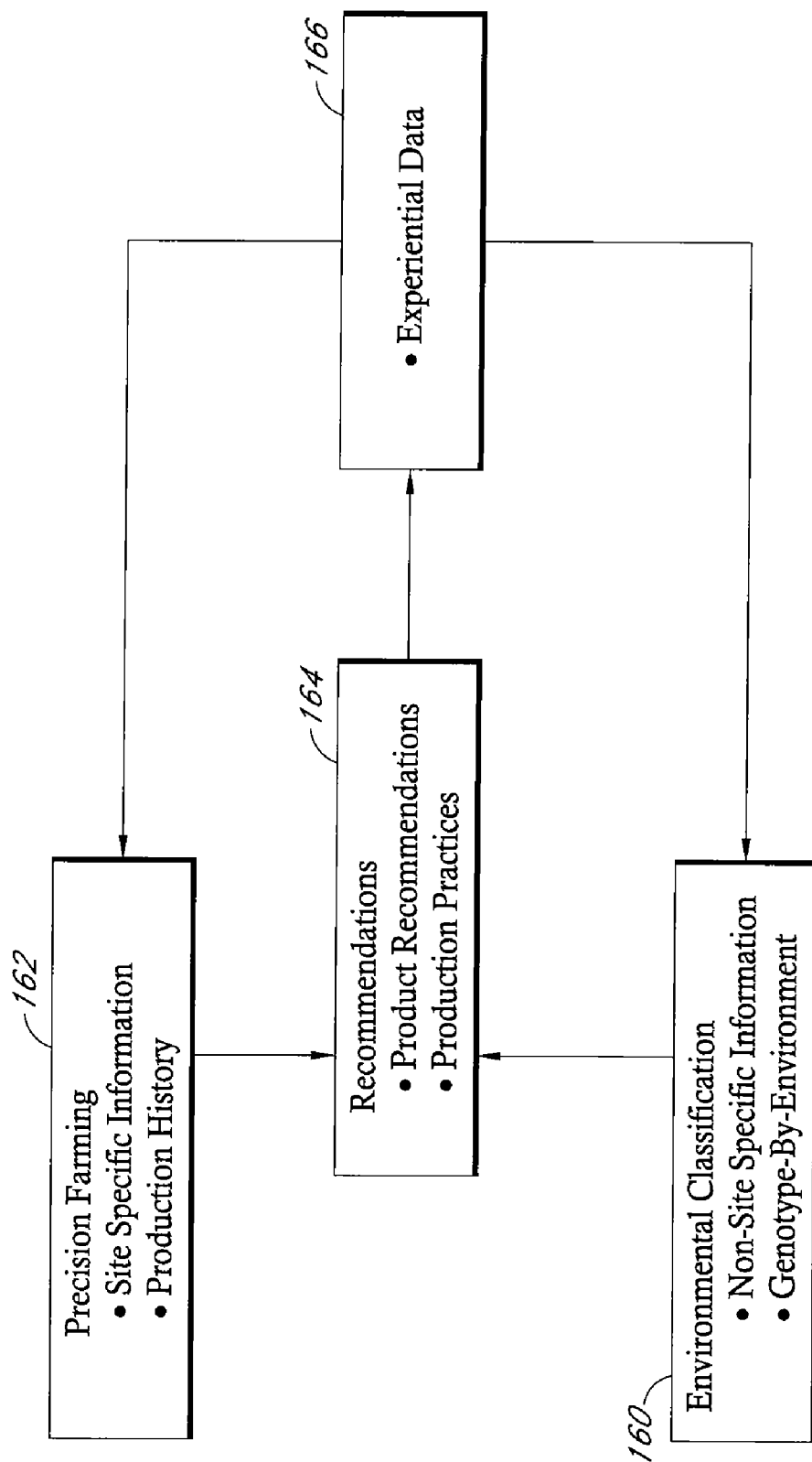


FIG. 13

170

Site Specific Information

Location 172

Environment and Production Information

Maturity Days 176

Input Traits 178

Output Traits 180

Seed Treatment 182

Tillage Practices 174

Planting Population 184

Nitrogen Utilization 186

Drought Frequency 187

Select Hybrid

<u>Hybrid Name</u>	<u>Hybrid Rank</u>	<u>Risk Assessment</u>
Hybrid1	99%	0.075 prob
Hybrid2	89%	0.15 prob

189

188

FIG. 14

200

X

Site Specific Information

Location

Soil Type ▼

Acres

Import Precision Farming Data

Import Environment Frequency Data

Set Production Practices

Set Environmental Assumptions

Set Risk Levels

Max Number of Hybrids: ▼

Portfolio Results

Product	Acres	Hybrid Rank	Risk Assessment	Revenue Assurance
Hybrid1	Acres1	1 (97%)	.15 prob	\$
Hybrid2	Acres2	3 (87%)	.20 prob	\$
Hybrid3	Acres3	2 (92%)	.03 prob	\$

214
216
217
218
219

Generate Precision Farming Information

FIG. 15

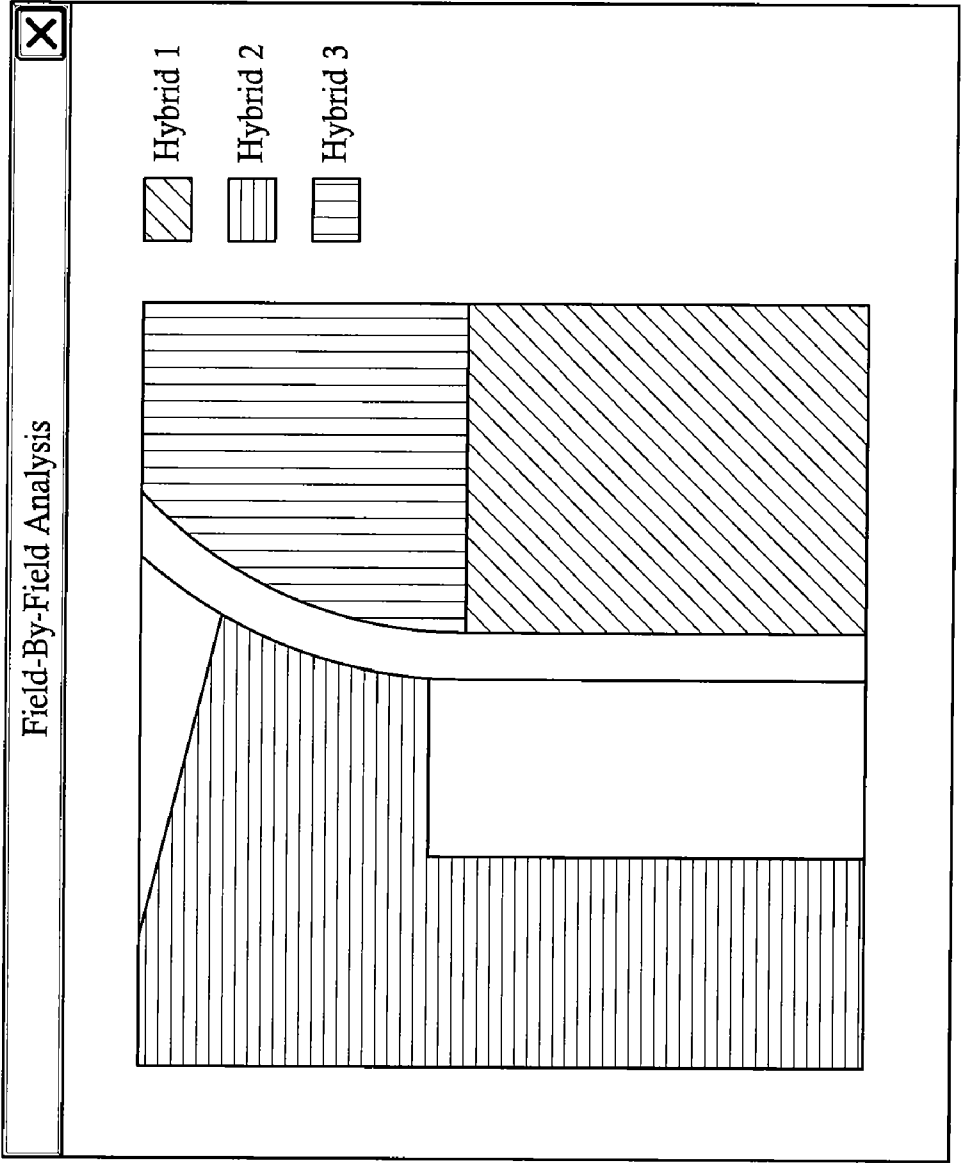


FIG. 16

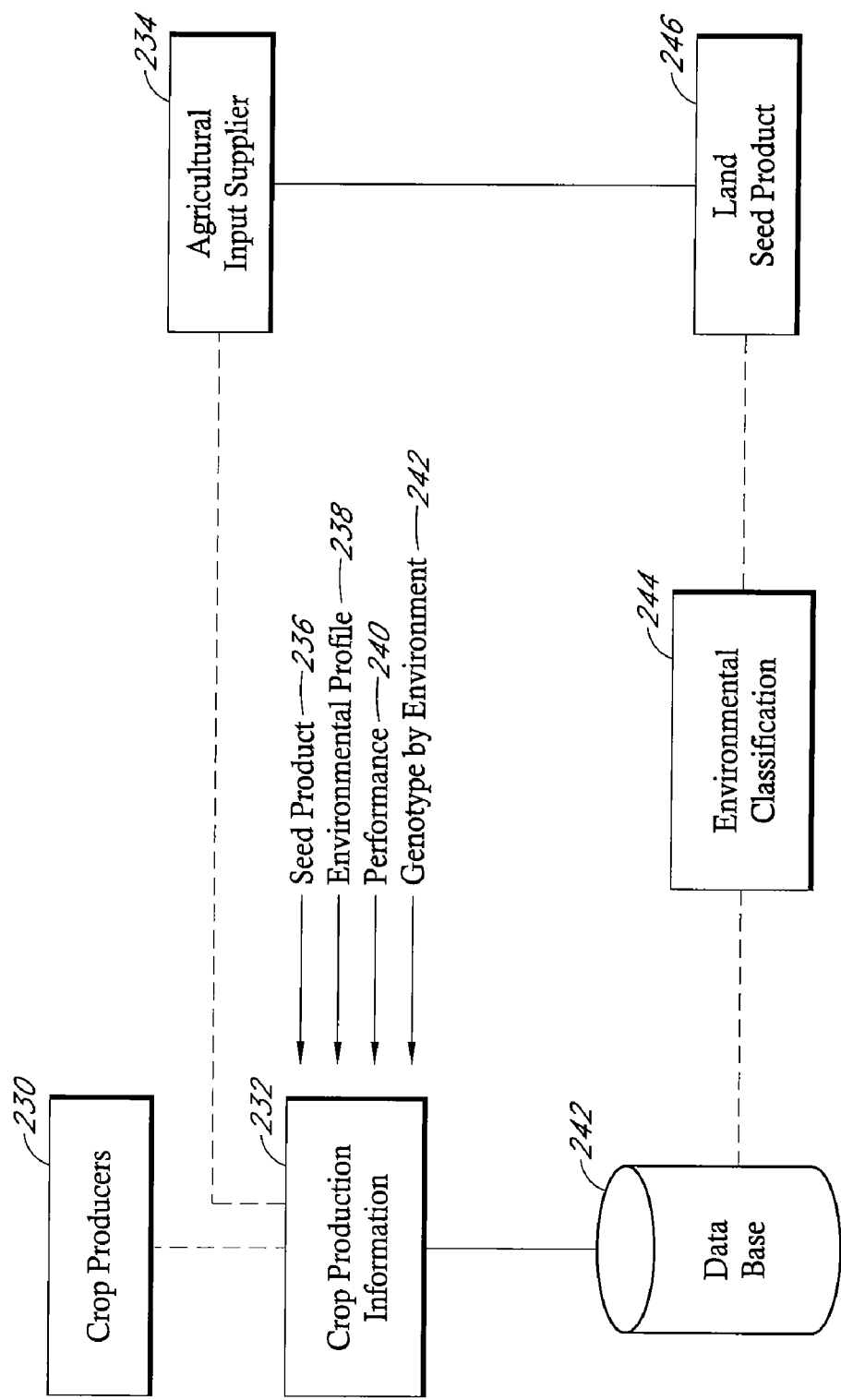


FIG. 17

METHOD AND SYSTEM FOR USE OF ENVIRONMENTAL CLASSIFICATION IN PRECISION FARMING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119 of a provisional application Ser. No. 60/689,716 filed Jun. 10, 2005, which application is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The present invention provides for computer-implemented methods and related methods to assist a crop producer or agricultural input supplier in selecting and/or classifying agricultural inputs, such as seed products to use in one or more fields, utilizing environmental classification information as well as precision agriculture information and methodologies.

[0003] The problem is generally described in the context where the seed products are corn hybrids. The current industry-wide approach to delivering product performance information for use in hybrid selection by producers is to use numerous comparative yield measurements from recent years (primarily the most recent year) and the geography considered relevant to the producer. Use of recent product performance data in selection of hybrids is not completely indicative of future hybrid performance as environmental and biotic factors vary from year to year, including extreme weather events, such as drought or flooding and pest or disease prevalence. Moreover, this approach does not fully take into account environmental and biotic factors important to a hybrid's performance. Furthermore, this approach lacks the full assessment of the relevance of the information generated by the trials to the relative performance of cultivars (genotype by environment interaction), for example genetic correlations. It assumes recent experience is the best predictor of future relative hybrid performance, regardless of how representative the recent experience may or may not be of the long-term environmental profile of the producer's land base.

[0004] In addition, this selection approach does not take into account a producer's objectives for productivity, nor does it allow for objective and specific recommendations of seed products or other crop product considerations, for example, fertilizer types or irrigation needs, for a particular land base so that producers may minimize their risk of unexpected performance occurrences. Although risk is uncertain, it is manageable.

[0005] What is needed is a method for product selection that is useful in characterizing relative performance of different seed products so that risk can be managed.

SUMMARY OF THE INVENTION

[0006] Therefore it is a primary object, feature, or advantage of the present invention to improve over the state of the art.

[0007] Another object, feature, or advantage of the present invention is to provide a method to assist customers, including producers, in managing risks associated with crop production.

[0008] Yet another object, feature, or advantage of the present invention is to assist customers and others in understanding relative performance of different agricultural inputs, including seed products, under the same or similar environmental conditions.

[0009] A still further object, feature, or advantage of the present invention is to assist customers and others in understanding relative performance of an agricultural input, such as a seed product, under a range of environmental conditions.

[0010] Another objective, feature, or advantage of the present invention is to assist producers in selecting the best seed product for a particular location or regions within a land base.

[0011] It is a further object, feature, or advantage of the present invention to describe genotype-by-environment interactions that may affect performance of a seed product.

[0012] It is a further object, feature, or advantage of the present invention to improve product selection decisions for regions within a land base.

[0013] A further object, feature, or advantage of the present invention is to increase the likelihood of high product performance.

[0014] A further object, feature, or advantage of the present invention is to increase yield advantage of a product.

[0015] Another object, feature, or advantage of the present invention is to assist customers in selection of these products most adapted to regions within their land base.

[0016] A further object, feature, or advantage of the present invention is to use genotype by environment information to capture more data from a broader area to use for a localized area.

[0017] Yet another object, feature, or advantage of the present invention is to increase a producer's confidence in planning recommendations.

[0018] Yet another object, feature, or advantage of the present invention is to use genotype by environment interactions to categorize particular land bases into different environmental classifications.

[0019] A still further object, feature, or advantage of the present invention is to allow for the creation of an environmental profile for all or part of a particular land base.

[0020] A still further object, feature, or advantage of the present invention is to use precision agriculture data obtained from the producer to assist in providing an environmental classification for different agricultural inputs, including seed products.

[0021] A still further object, feature, or advantage of the present invention is to use precision agriculture data obtained from the producer to assist in providing an environmental classification for different agricultural inputs, without the need for location information or producer information.

[0022] It is to be understood that the present invention has a number of different aspects, each of which may demonstrate one or more of these and/or other objects, features, or

advantages of the present invention as will become apparent from the specification that follows.

[0023] The present invention has numerous aspects that build upon the application of environment classification and information extracted from hybrids. These various aspects are often described herein from the perspective of a seed company and a crop producer and when a specific crop is used as an example, the exemplary crop is usually corn. Of course, aspects of the present invention are applicable to many different types of companies or individuals and many different types of agricultural inputs and/or products. Also, the present invention is of use not just to crop producers but others who have interest in comparing relative performance of agricultural inputs under different conditions. This could include, for example, downstream users of agricultural products, such as agricultural input suppliers such as equipment manufacturers, chemical producers, landlords, or others who have interests related to agricultural production.

[0024] The present invention relates to improved understanding of genotype-by-environment interactions and applications of those methods in a variety of contexts for a variety of purposes.

[0025] According to one aspect of the present invention a computer-assisted method of selecting seed products for planting by a crop producer associated with a field is provided. Each of the seed products has a genotype. The method includes dividing the field into regions, providing an environmental profile for each of regions, determining a recommendation of a seed product to plant within each of the regions based on the environmental profile and performance of the genotype of each of the seed products in the environmental profile of the regions, and providing an output identifying the seed product to plant within each of the regions. The environmental profile can include an environmental classification associated with each of the regions.

[0026] Determination of a recommendation is preferably at least partially based on genotype-by-environment and/or genotype-by-environment-by-management interactions. The recommendation may provide for planting a plurality of seed products or a single seed product within the field. The method may also include determining an overall environmental profile for the field based on the environmental profile for each of the regions.

[0027] According to another aspect of the present invention, a computer-assisted method of selecting seed products for planting by a crop producer associated with a land base is provided. The method includes dividing the land base into a plurality of regions, classifying each of the regions with an environmental classification, determining a recommendation of a seed product to plant within each of the regions based on the environmental classification, and providing an output comprising identification of the at least one seed product to plant within each of the regions.

[0028] According to another aspect of the present invention, a method to assist in classifying agricultural inputs is provided. The method includes collecting crop production information from multiple crop producers. The crop production information includes the type of seed product, environmental profile information, and performance information. The crop production information is stored in a data base and a set of environmental classifications is determined to

describe the agricultural inputs at least partially based on the environmental profile information and performance information. The crop production information may also include genotype-by-environmental information as well as location information. Location information and identity of the producer may also be excluded from the crop production information.

[0029] According to another aspect of the invention, a method for making a recommendation for a seed product to plant within a land base is provided. The method includes collecting crop production information from a plurality of crop producers over a plurality of geographically diverse locations, determining environmental classifications using the crop production information, classifying the land base with at least one environmental classification, and determining the recommendation for a seed product to plant within the field based on the environmental classification.

BRIEF DESCRIPTION OF THE FIGURES

[0030] **FIG. 1** is a flow diagram illustrating one process for determining genotype-by-environment interactions and using that information in categorizing land bases into different environmental classifications.

[0031] **FIG. 2A** to **FIG. 2C** provide an example of genotype by environment interactions and cross-over interactions between two different varieties in four different environmental classes.

[0032] **FIG. 3** illustrates environment-standardized GGE biplot of grain yield of 18 maize hybrids (H1-H18) grown in 266 environments over three years stratified by state.

[0033] **FIG. 4** illustrates environment-standardized GGE biplot of grain yield of 18 maize hybrids (H1-H18) grown in 266 environments over three years stratified by environmental class.

[0034] **FIG. 5** illustrates one possible schematic for categorizing different land bases into environmental classifications based on temperatures, solar radiation, and length of photoperiod.

[0035] **FIG. 6** is a bar graph representation of the frequency of various environmental classes among target population of environments (TPEs) or multi-environment trials (METs).

[0036] **FIG. 7** illustrates potential categories of environmental classes identified throughout the United States in 1988 and their locations; these include temperate, temperate dry, temperate humid, high latitude, and subtropical classes.

[0037] **FIG. 8** is a flow diagram illustrating information flow from an environmental profile and a producer profile to providing recommendations to a producer according to one embodiment of the present invention.

[0038] **FIG. 9** is block diagram illustrating a system for determining product recommendations according to one embodiment of the present invention.

[0039] **FIG. 10** is block diagram illustrating a system for determining product recommendations according to one embodiment of the present invention.

[0040] **FIG. 11** is a screen display according to one embodiment of the present invention.

[0041] FIG. 12 is a screen display showing a product portfolio according to one embodiment of the present invention.

[0042] FIG. 13 is a flow diagram illustrating information flow for one embodiment of a precision farming application of the present invention.

[0043] FIG. 14 is a screen display for one embodiment of an application of the present invention.

[0044] FIG. 15 is a screen display for one embodiment of an application of the present invention.

[0045] FIG. 16 is a screen display for one embodiment of the present invention showing field-by-field product recommendations.

[0046] FIG. 17 is a flow diagram illustrating information flow according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0047] The present invention provides methods which can be used to assist customers, including producers or others in managing risks related to crop production. Managing risks can be performed by understanding the relative performance of different agricultural inputs, including seed products, under the same or similar environmental conditions as well as understanding variations in the performance of the same agricultural input over a range of environmental conditions. By being able to describe and understand these variations in performance, decisions can be made which are consistent with overall business and/or production objectives and limit risk associated with variations in environmental conditions. These decisions can include what seed products or combination of seed products to plant, where to plant different seed products, what other agricultural inputs to use, and what crop management practices to apply. Utilizing precision agriculture techniques, these decisions can be made for multiple regions or locations within a land base.

[0048] One method to manage risks associated with crop production uses knowledge of genotype-by-environment interactions to assist a producer or other customer in selecting seed products to plant in one or more regions within a field. A “genotype” is generally defined as a cultivar, genetically homogenous (lines, clones), a hybrid of two or more parents, or heterogeneous (open-pollinated populations). An “environment” is generally defined as a set of conditions, such as climatic conditions, soil conditions, biotic factors (such as, without limitation, pests and diseases) and/or other conditions that impact genotype productivity. “Management” as used in this context generally refers to production management decisions, such as, but not limited to crop production practices. In addition, the present invention allows for the use of environmental characterizations to assist in describing genotype-by-environment interactions. It is to be understood that the term “genotype-by-environment” (G×E) is to encompass what is sometimes known or referred to as “genotype-by-environment-by management” (G×E×M) as the environment associated with a plant may include management practices which affect the environment (for example, irrigation may be considered a management practice, but use of irrigation affects the growing environment).

[0049] Following, is an exemplary description regarding the use of G×E interactions and environmental classification.

G×E and Environmental Classification

[0050] Genetic manipulation alone does not ensure that a plant will perform well in a specific environment or for that matter a wide range of environments year after year. In other words, there is no one genotype that is likely to performance best in all environments or under all management practices. The performance or phenotype results from an interaction between the plant’s genotype and the environment and the management practices used.

[0051] It is to be understood that there are some inherent difficulties in understanding such interactions. An environment at a given location changes over the years making multi-environment trials (METs) performed in the same location limited as to inferences about future crop performance. Furthermore, inferences about a crop’s future performance in different locations depend on whether the target population of environments (TPEs) is well sampled since the environment varies between different locations in one year.

[0052] To assist in analyzing such interactions, the present invention preferably uses environmental classification techniques. The environmental classification techniques are used, preferably with a large set of data to relate performance of different genotypes to different environments. Environmental classification is then used when selecting the best seed products for a particular land base. Thus, for example, a producer can use environmental classification to select the best seed products for their land base based on the expected environmental conditions. Alternatively, the producer may diversify and select a combination of seed products based on a range of expected environmental conditions to thereby manage risks associated with environmental variability. Of course, environmental classification can be used by not just producers but others having interest in agricultural production.

[0053] FIG. 1 provides an overview of one G×E paradigm where G×E knowledge 12 is used in planning and positioning 18. G×E knowledge 12 can be applied to crop modeling 14. Crop modeling 14 and G×E knowledge 12 may either alone or together be used to classify environments. The G×E knowledge 12 and classified environments may be used in facilitating the positioning and/or planning 18 strategies, such as characterization of products, resource efficiency, risk management, product positions, and product selection.

[0054] Subsequent to positioning and planning, the producer will grow the selected products 26 and measure the performance results 24. The producer may also collect environmental and physiological landmark data 28 and in conjunction with performance results 24 use it in analysis 20. Analysis of environmental and physiological landmark data 28 and performance results 24 may undergo analysis 20 using G×E analysis tools or period-of-years database 22.

Building an Environmental Classification System

[0055] The effectiveness of a product evaluation system for genotype performance largely depends on the genetic correlation between multi-environment trials (MET) and the target population of environments (TPE) (Comstock, R. E. 1977. ‘Proceedings of the International Conference on

Quantitative Genetics, Aug. 16-21, 1976' pp. 705-18. Iowa State University Press. Ames, USA.). For example, previous characterizations of maize environments relied mainly on climatic and soil data (e.g. Hartkamp, A. D., J. W. White, A. Rodriguez Aguilar, M. Bänziger, G. Srinivasan, G. Granados, and J. Crossa. 2000. Maize Production Environments Revisited: A GIS-based Approach. Mexico, D. F. CIMMYT.; Pollak, L. M., and J. D. Corbett. 1993. Agron. J. 85:1133-1139; Runge, E. C. A. 1968. Agron. J. 60:503-507.). While useful to describe environmental variables affecting crop productivity, these efforts did not quantify the impact of these variables on the genetic correlations among testing sites. Consequently, plant breeders have more extensively used characterizations of environments based on similarity of product discrimination in product evaluation trials (e.g. Cooper, M., D. E. Byth, and I. H. DeLacy. 1993. Field Crops Res. 35:63-74.). However, these efforts frequently fail to provide a long-term assessment of the target population of environments (TPE), mainly due to the cost and impracticality of collecting empirical performance data for widespread and long-term studies.

[0056] The present invention provides a modern approach of product evaluation where a TPE is described. The description of a TPE includes classifying the land base into an environmental class and assessing the frequency of occurrence of the range of environments experienced at a given location. The present inventors contemplate that areas of adaption (AOA) could also be evaluated. As used herein AOA refers to a location with the environmental conditions that would be well suited for a crop or specific genotype. Area of adaption is based on a number of factors, including, but not limited to, days to maturity, insect resistance, disease resistance, and drought resistance. Area of adaptability does not indicate that the crop will grow in every location or every growing season within the area of adaption or that it will not grow outside the area. Rather it defines a generally higher probability of success for a crop or genotype within as opposed to outside that area of adaptation.

[0057] The environmental information collected may be used to develop an environmental database for research locations. Initially, multiple environment trials are performed by planting different genotypes available from a variety of sources, e.g. germplasm, inbreds, hybrids, varieties in multiple environments. These trials aid the determination of whether the TPEs are homogenous or should be categorized into different environmental classifications. The performance data of these genotypes and environmental and/or physiological landmark data from the MET are collected and entered into a data set. For example, performance data collected for a genotype of corn may include any of the following: yield, grain moisture, stalk lodging, stand establishment, emergence, mid silk, test weight, protein, oil, and starch. Yield refers to bushels of grain per acre. Grain moisture refers to a moisture determination made from each plot at harvest time, using an instrument such as an electrical conductance moisture meter. Stalk lodging refers to the determination of the number of broken stalks in each plot prior to harvest. Stand establishment refers to the differences between the desired planting rate for each hybrid and the final stand. Emergence refers to an emergence count made on each plot after plant emergence where emergence percentage may be computed based on the number of plants and the number of kernels planted. The mid silk date is the Julian day of the year in which 50% of the plants show silks at one

site in a region. The test weights are typically reported as pounds per bushel on grain samples at field moisture. Protein, oil and starch are typically reported as a percent protein, oil, and starch content at a designated percent grain moisture on dried samples using standard methods, for example, a near infrared transmittance whole grain analyzer.

[0058] One skilled in the art would be familiar with performance data collected for other crops, for example, soybeans, wheat, sunflowers, canola, rice and cotton. Performance data for soybeans include, without limitation, relative maturity, plant height, lodging score, seed size, protein and oil percentage, Phytophthora resistance genes, Phytophthora partial resistance, Sclerotinia rating, and yield. Relative maturity refers to a determination that is designed to account for factors, such as soybean variety, planting date, weather, latitude and disease that affect maturity date and number of days from planting to maturity. Plant height refers to a determination of the soybean plant's height, usually determined prior to harvest. Lodging, traditionally, the vertical orientation of the plant, i.e. the degree to which the plant is erect. The lodging of a soybean plant is traditionally rated by researchers using a scale of 1 to 9 as follows: 1.0=almost all plants erect, 3.0=either all plants leaning slightly, or a few plants down, 5.0=either all plants leaning moderately (45° angle), or 25-50% down, 7.0=either all plants leaning considerably, or 50-80% down, 9.0=all plants prostrate. The seed size of a soybean plant typically refers to thousands of seeds per pound. Protein and oil percentage analysis may be determined using near infrared transmittance technology and reported at 13% moisture. Phytophthora resistance genes may be determined using a hypocotyl inoculation test with several races of Phytophthora to determine the presence or absence of a particular Rps gene in a soybean plant. Soybeans may also be evaluated for phytophthora partial resistance using a ratings system, where ratings of 3.0 to 3.9 are considered high levels of partial resistance, ratings of 4.0 to 5.9 are considered moderate, ratings over 6.0 indicate very little partial resistance or protection against Phytophthora. Soybeans may also be evaluated for partial resistance to Sclerotinia. Yield refers to bushels per acre at 13 percent moisture.

[0059] Typical performance data for wheat includes, without limitation, test weight, protein percent, seed size, percent lodging, plant height, heading date, powdery mildew, leaf blotch complex (LBC), Fusarium head scab (FHS), flour yield, and flour softness. Test weight refers to a determination of pounds/bushell using harvest grain moisture. Seed size refers to thousands of harvested seeds per pound. Percent lodging as described previously refers to a rating system used to estimate the percent of plants that are not erect or lean more than 45 degrees from vertical. Plant height refers to the distance from the soil surface to the top of the heads. Heading date refers to the average calendar day of the year on which 50 percent of the heads are completely emerged. Wheat infected with powdery mildew (PM) may be determined using a scale system where each plot is rated based on a 0 to 10 scale where: 0=0 to trace % leaf area covered; 1=leaf 4 with trace -50%; 2=leaf 3 with 1-5%; 3=leaf 3 with 5-15%; 4=leaf 3 with >15%; 5=leaf 2 with 1-5%; 6=leaf 2 with 5-15%; 7=leaf 2 with >15%; 8=leaf 1 with 1-5%; 9=leaf 1 with 5-15%; and 10=leaf 1 with >15% leaf area covered (leaf 1=flag leaf). This scale takes into account the percentage leaf area affected and the progress of the disease upward on the plants. Leaf blotch complex

(LBC) caused by *Stagonospora nodorum*, *Pyrenophora tritici-repentis* and *Bipolaris sorokiniana* for example may be determined when most varieties are in the soft dough growth stage and rated based on the percentage of flag leaf area covered by leaf blotches. Fusarium head scab (FHS) caused by *Fusarium graminearum* for example may be determined when plants are in the late milk to soft dough growth stage and each plot is rated based on a disease severity estimate as the average percentage of spikelets affected per head. Flour yield refers to the percent flour yield from milled whole grain. Flour softness refers to the percent of fine-granular milled flour. Values higher than approximately 50 indicate kernel textures that are appropriate for soft wheat. Generally, high values are more desirable for milling and baking.

[0060] Typical performance data for sunflower includes, without limitation, resistance to aphids, neck breakage, brittle snap, stalk breakage, resistance to downy mildew (*Plasmopara halstedii*), height of the head at harvest, seed moisture, head shape, hullability, resistance to the sunflower midge, *Contarinia schulzi*, percentage of oil content, seed size, yield, seedling vigor, and test weight. Resistance to aphids refers to a visual ratings system indicating resistance to aphids based on a scale of 1-9 where higher scores indicate higher levels of resistance. Neck breakage refers to a visual ratings system indicating the level of neck breakage, typically on a scale from 1 to 9 where the higher the score signifies that less breakage occurs. Brittle snap refers to a visual rating system indicating the amount of brittle snap (stalk breakage) that typically occurs in the early season due to high winds. The ratings system is based on a scale, usually ranging from 1-9, with a higher score denoting the occurrence of less breakage. A sunflower's resistance to Downy Mildew (*Plasmopara halstedii*) may be determined using a visual ratings scaled system with 9 being the highest and 1 the lowest. A higher score indicates greater resistance. Height of the head at harvest refers to the height of the head at harvest, measured in decimeters. Seed moisture refers to a determination of seed moisture taken at harvest time, usually measured as a percentage of moisture to seed weight. Head shape of a sunflower is measured visually using a scale system where each plot is rated based on a 1 to 9 scale where: 1=closed "midge" ball; 2=trumpet; 3=clam; 4=concave; 5=cone; 6=reflex; 7=distorted; 8=convex; 9=flat. Hullability refers to the ability of a hulling machine to remove seed hulls from the kernel, typically measured on a 1-9 scale where a higher score reflects better hullability. Resistance to the sunflower midge, *Contarinia schulzi*, is determined based on head deformation which is rated on a 1-9 scale where: 9=no head deformation (fully resistant), 5=moderate head deformation, 1=severe head deformation (fully susceptible). The percentage of oil content from the harvested grain is measured and adjusted to a 10% moisture level. The oil content of a sunflower seed may be measured for various components, including palmitic acid, stearic acid, oleic acid, and linoleic acid, using a gas chromatograph. Seed size refers to the percentage of grain that passes over a certain size screen, usually "size 13." Seedling vigor refers to the early growth of a seedling and is often times measured via a visual ratings system, from 1-9, with higher scores indicate more seedling vigor. Yield is measured as quintals per hectare, while test weight of seed is measured as kilograms per hectoliter.

[0061] Typical performance data for canola includes, without limitation, yield, oil content, beginning bloom date, maturity date, plant height, lodging, seed shatter, winter survival, and disease resistance. Yield refers to pounds per acre at 8.5% moisture. Oil content is a determination of the typical percentage by weight oil present in the mature whole dried seeds. Beginning bloom date refers to the date at which at least one flower is on the plant. If a flower is showing on half the plants, then canola field is in 50% bloom. Maturity date refers to the number of days observed from planting to maturity, with maturity referring to the plant stage when pods with seed color change, occurring from green to brown or black, on the bottom third of the pod bearing area of the main stem. Plant height refers to the overall plant height at the end of flowering. The concept of measuring lodging using a scale of 1 (weak) to 9 (strong) is as previously described. Seed shatter refers to a resistance to silique shattering at canola seed maturity and is expressed on a scale of 1 (poor) to 9 (excellent). Winter survival refers to the ability to withstand winter temperatures at a typical growing area. Winter survival is evaluated and is expressed on a scale of 1 to 5, with 1 being poor and 5 being excellent. Disease resistance is evaluated and expressed on a scale of 0 to 5 where: 0=highly resistant, 5=highly susceptible. The Western Canadian Canola/Rapeseed Recommending Committee (WCC/RRC) blackleg classification is based on percent severity index described as follows: 0-30% =Resistant, 30%-50%=Moderately Resistant, 50%-70%=Moderately Susceptible, 70%-90%=Susceptible, and >90%=Highly susceptible.

[0062] Typical performance data for cotton includes, without limitation, yield, turnout, micronaire, length, fiber strength of cotton and color grade. Yield is measured as pounds per acre. Turnout refers to lint and seed turnout which is calculated as the percentage of lint and seed on a weight basis as a result of ginning the sub sample from each treatment. Micronaire refers to fiber fineness and maturity and are measured using air flow instrument tests in terms of micronaire readings in accordance with established procedures. Fiber length is reported in $\frac{1}{32}$ of an inch or decimal equivalents. Fiber strength is measured in grams per tex and represents the force in grams to break a bundle of fibers one tex unit in size. Color grade for cotton takes into consideration the color, fiber color and whiteness of cotton leaves. Color grade may be determined using a two digit scale. The two digit number is an indication of the fiber color and whiteness (i.e. 13, 51, or 84). The first digit can range from 1 to 8 representing overall color with 1 being the best color and 8 representing below grade colors. The second digit represent a fiber whiteness score. This number ranges from 1 to 5, with 1 representing good white color and 5 representing yellow stained. The second number in the overall color grade represents the leaf score and represents leaf content in the sample.

[0063] Typical performance data for rice includes, without limitation, yield, straw strength, 50% Heading, plant height, and total milling, and total milling. Yield is measured as bushels per acre at 12% moisture. Straw Strength refers to lodging resistance at maturity and is measured using a numerical rating from 1 to 9 where 1=Strong (no lodging); 3=Moderately strong (most plants leaning but no lodging); 5=Intermediate (most plants moderately lodged); 7=Weak (most plants nearly flat); and 9=Very weak (all plants flat). 50% heading refers to the number of days from emergence

until 50% of the panicles are visibly emerged from the boot. Plant height is the average distance from the soil surface to the tip of erect panicle. Total milling refers to the total milled rice as a percentage of rough rice. Whole milling refers to rice grains of $\frac{3}{4}$ length or more expressed as a percentage of rough rice.

[0064] The environmental and physiological landmark data may be historical using historical meteorological information along with soils and other agronomic information or collected using National Oceanic and Atmospheric Association and/or other public or private sources of weather and soil data. Potential environmental and physiological landmark data that may be collected includes but is not limited to wind, drought, temperature, solar radiation, precipitation, soil type, soil pH, planting and harvesting dates, irrigation, tiled area, previous crop, fertilizer including nitrogen, phosphorous, and potassium levels, insecticide, herbicide, and biotic data, for example, insects and disease. The environmental and physiological landmark data may then be analyzed in light of genotype performance data to determine G×E interactions.

Models

[0065] Several models for determining G×E interactions exist. Base models group or classify the locations used to test the hybrids, include several variance components, and stratify the hybrids, for example, according to locations among station-year combinations, locations, or other chosen variances.

[0066] For example, as shown in Table 1, one base model Year Station (YS) groups the locations by year-stations where a year-station designates a unique site or location by year. Other variances include blocks within locations within year-stations, hybrids, hybrids by year-station divided by the sum of hybrids by locations within year station locations as well as a residual. The YS model is disadvantageous in that a given location's environment will vary over time so that the G×E information gleaned from the model may not be relevant for predicting hybrids that will perform well in the same location next year.

[0067] Another model for determining G×E interactions disclosed in Table 1, groups different sites by location. Other variances for the G×E model include blocks within locations, hybrids, hybrids by locations, as well as a residual. However, the G×E model is disadvantageous in that a genotype grown in locations with differing environmental conditions may have similar performance results, complicating the analysis of the specific environmental conditions that play a role in contributing to genotype performance and reducing the certainty of predicting product performance.

[0068] Unlike the previous models mentioned, the present inventors contemplate determining G×E interactions using a model referred to herein as Environmental Classification that groups locations by environmental classifications. Thus, variances for this model include locations within environmental classifications, blocks within locations within environmental classifications, hybrids, hybrids by environmental classifications divided by hybrids by locations within environmental classifications and a residual.

TABLE 1

Models for determining G × E interactions			
Model	Year-Station	G × E	Environmental Classification
Variance for location	Location within year-station	Location	Location within environmental classification
Variance for location	blocks within locations within year-station	blocks within locations	blocks within locations within environmental classifications
Variance for hybrids	hybrids	hybrids	hybrids
Stratifications	hybrid by year-station/hybrids by locations within locations	hybrid by locations	hybrid by environmental classifications/hybrid by locations within environmental classifications

[0069] Burdon has shown that genetic correlation between G×E interactions can be estimated. (Burdon, R. D. 1977. *Silvae Genet.*, 26: 168-175.). G×E analysis may be performed in numerous ways. G×E interactions may be analyzed qualitatively, e.g. phenotype plasticity, or quantitatively using, for example, an analysis of variance approach. (Schlichting, C. D. 1986. *Annual Review of Ecology and Systematics* 17: 667-693.). Statistical analysis of whether a G×E interaction is significant and whether environmental changes influence certain traits, such as yield performance, of the genotypes evaluated may be performed using any number of statistical methods including but not limited to, rank correlation, analysis of variances, and stability.

Rank Correlation

[0070] The most basic categorization of G×E interaction is to evaluate G×E interactions by performing a rank correlation according to standardized tests, for example, Spearman. The Spearman rank correlation may be performed to examine the relationships among genotypes in different environments, for example, crossover interactions that occur when two genotypes change in rank order of performance when evaluated in different environments. FIG. 2 illustrates an example of G×E interactions and cross-over interactions (COI) between two different varieties, Var A and Var B, in four different environmental classes, Env 1, Env 2, Env 3 and Env 4. FIG. 2A shows that Var A and Var B out-perform each other in different environments indicating the occurrence of both G×E and COI. FIG. 2B shows that Var A performed better than Var B in each environment, indicating G×E interactions but no COI. In contrast, FIG. 2C shows that Var A and Var B each performed consistently with respect to each other in all four environments, indicating lack of G × E interactions.

Analysis of Variance (ANOVA)

[0071] Alternately, G×E interactions may be analyzed using an analysis of variance method (ANOVA) (Steel, R. G. D and J. H. Torrie. 1980. *Principles and Procedures of Statistics*, 2nd edition) over environments to determine the significance of genotypes, environments and G×E interactions. G×E interactions may also be analyzed using ASREML (Gilmour, A. R., Cullis, B. R., Welham, S. J. and Thompson, R. 2002 *ASReml Reference Manual* 2nd edition,

Release 1.0 NSW Agriculture Biometrical Bulletin 3, NSW Agriculture, Locked Bag, Orange, NSW 2800, Australia.) for the computation of variance components, and the generation of GGE biplots (Cooper, M., and I. H. DeLacy. 1994. *Theor. Appl. Genet.* 88:561-572; Yan, W. and M. S. Kang. 2003. *GGE Biplot Analysis: A Graphical Tool for Breeders Geneticists, and Agronomists*. CRC Press. Boca Raton, Fla.). **FIG. 3** and **FIG. 4** illustrate environment-standardized GGE biplot of grain yield of 18 maize hybrids (H1-H18) grown in 266 environments over three years, stratified by state or by environmental class respectively.

Stability

[0072] Once certain genotypes are identified that perform well in a target environment they may be analyzed to determine which hybrids are more stable in yield or other metrics using various methods. One method uses a regression of genotypic performance on an environmental index. In general, the environmental index is the deviation of the mean phenotype at environment from the overall mean phenotype of all environments. Thus, the phenotype of an individual genotype with each environment is regressed on the environmental index, as described in Bernardo R. 2002. *Quantitative Traits in Plants*. Stemma Press, Woodbury, Minn. to generate a slope (b-value) for each genotype/cultivar evaluated. Other methods include the joint regression analysis method proposed by Perkins, J. M. and Jinks, J. L. 1968. *Heredity*. 23: 339-359, Finlay, K. W. and Wilkinson, G. N. 1963. *Aust. J. Res.* 14: 742-754 and Eberhart, S. A. and Russell, W. A. 1966. *Crop Sci.* 6:36-40 to calculate the regression coefficient (b), S.E. and variance due to deviation from regression (S_{2d}) as a parameter of stability and adaptability. The model described by Eberhart and Russell has the following formula:

$$P_{ij} = \mu + g_i + b_i t_j + \delta_{ij} + e_{ij}$$

where P_{ij} is the mean phenotype of genotype or cultivar i in location j,

[0073] μ is the grand mean across the whole experiment for all genotypes and locations,

[0074] g_i is the effect of genotype i across all locations

[0075] b_i is the linear regression of P_{ij} on t_j ,

[0076] t_j is the environmental index, that is the effect of environment j across all genotypes),

[0077] δ_{ij} is the deviation P_{ij} from the linear regression value for a given t_j and

[0078] e_{ij} is the within environment error.

Categorization of Land Bases into Environmental Classes

[0079] Using the information collected for or from G×E analysis, the land bases may be categorized into environmental classifications. **FIG. 5** illustrates one possible schematic for categorizing different land bases into environmental classifications. With reference to **FIG. 5**, one method of categorizing environmental classifications is illustrated as a flow chart. If all maximum temperatures are greater than 28° Celsius **42**, then the land base may be categorized as either Temperate Dry **54**, Temperate Humid **52**, Temperate **56**, or Subtropical **48**. If all maximum temperatures are greater to or equal to 30° Celsius and solar radiation is greater than 24 and 21 at a given crop development stage, e.g. v7-R1, R3-R6

40, then the land base is characterized as Temperate Dry **54**. If the maximum temperature is not greater than or equal to 30° Celsius and solar radiation is not greater than 24 at a given crop development stage, e.g. V7-R1 and 21 for R3-R6 respectively **40**, then the land base is characterized as Temperate **56**. However, if the maximum temperature is less than 30° Celsius and solar radiation is greater than 24 and 21 at a given crop development stage **50**, then the land base is characterized as Temperate Humid **52**. If the maximum temperature is not less than 30° Celsius and solar radiation is not greater than 24 and 21 at a given crop development stage **50**, then the land base is characterized as Temperate **56**. If all maximum temperatures **42** for the land base are less than 28° Celsius than the land base is characterized as High Latitude **44**. In contrast, if all maximum temperatures **42** for the land base are not less than 28° Celsius and the land base has a photoperiod less than 13.4 hours/day **46**, then the land base is Subtropical **48**.

[0080] Categorizing land bases into environmental classifications has several advantages. First, environmental classifications can bring an understanding of the various environments under which crops are produced. Second, occurrence probabilities for each environmental category can be assigned to each geographic location and the frequency of the classifications determined using routine methods. **FIG. 6** is a bar graph representation of the frequency of various environmental classes among TPEs or METs. The frequency for each environmental class, e.g. temperate, temperate dry, temperate humid, high latitude, and subtropical, is given as a percent of the total TPE or MET tested in given year or across years. **FIG. 7** illustrates potential categories of environmental classes identified throughout the United States in 1988 and their locations; these include temperate, temperate dry, temperate humid, high latitude, and subtropical classes. It will be apparent to one skilled in the art that other environmental classifications may be added as identified or deemed relevant to G×E interactions for various crops.

[0081] Some of the environmental classification may be defined using general characteristics of climates. For example, temperate may be used to refer to regions in which the climate undergoes seasonal change in temperature and moisture; typically these regions lie between the Tropic of Capricorn and Antarctic circle in the Southern Hemisphere and between the Tropic of Capricorn and the Arctic circle in the Northern Hemisphere. Temperate humid may refer to regions in which the climate undergoes seasonal change in temperature and moisture and has more humidity than a temperate environment. High latitude as an environmental class may refer to regions that have a longer photoperiod than and is typically north of a particular latitude. A subtropical class may refer to regions enjoying four distinct seasons usually with hot tropical summers and non-tropical winters with a shorter photoperiod/day length; typically these regions lie between the ranges 23.5-40° N and 23.5-40° S latitude. The environmental classes may also be defined by biotic factors, such as diseases, insects, and/or characteristic of a plant. For example, an ECB class may refer to regions having European Corn Borers (ECB) or the suspected presence of ECB as evidenced by preflowering leaf feeding, tunneling in the plant's stalk, post flowering degree of stalk breakage and/or other evidence of feeding. The environmental class Brittle may be used to refer to regions where stalk breakage of corn occurs or is apt to

occur near the time of pollination and is indicative of whether a hybrid or inbred would snap or break near the time of flowering under severe winds.

[0082] It is to be understood that the environmental classifications may be used and defined differently for different crops/genotypes and that these definitions may vary from year to year, even for the same crops or genotypes. For example, in 2000-2003, trials conducted studying G×E interactions among Comparative Relative Maturity (CRM) hybrids of CRM 103-113 in different environments identified seven different environmental classes—temperate, temperate dry, temperate humid, high latitude, subtropical, ECB, and brittle. For the study purposes, temperate was identified/defined as having a low level of abiotic stresses, a growing season adequate for CRM 103-113, and found to be frequent in Iowa and Illinois. Temperate dry was defined as temperate with some level of water and/or temperature stress and found to be frequent in Nebraska, Kansas, and South Dakota. Temperate Humid was defined as similar to the temperate environmental class but had a complex of biotic factors, such as leaf disease that may differentially affect product performance. Temperate humid was also characterized as having a temperature and solar radiation lower than that identified in the temperate environmental class and found to be frequent in Indiana, Ohio, and Pennsylvania. The High Latitude environmental class was found to grow corn CRM 103 and earlier (growing hybrids) and experienced colder temperatures than the Temperate environmental class but with longer day-length. This environmental class was found to be frequent in Canada, North Dakota, Minnesota, Michigan, and Wisconsin. The fifth environmental class, Subtropical, was characterized as warm and humid with a short day-length and found frequently in the Deep South of the United States. Another environmental class identified was European Corn Borers (ECB) and defined as having *Bacillus thuringiensis* (Bt) hybrids that outyielded base genetics by at least 10%. The last environmental class Brittle defined areas with significant brittle damage with differential effect on products.

[0083] Once areas of land are categorized as environmental classes, these areas may be used in METs. Ultimately, the observed genotype performances in METs can be linked by the environmental class to the TPE. By evaluating product performance in a target environment, rather than merely performance differences in METs, genotype performance data from multiple test environments can be correlated to a target environment and used to predict product performance. This correlation between a genotype's performance and the target environment or environmental classification will lead to more precise product placement since the genotype performance is characterized within an environmental class in which it is adapted and most likely to experience after commercialization, consequently resulting in improved and more predictable product performance. The analysis of G×E interactions facilitates the selection and adoption of genotypes that have positive interactions with its location and its prevailing environmental conditions (exploitation of areas of specific adaption). G×E analysis also aids in the identification of genotypes with low frequency of poor yield or other performance issues in certain environments. Therefore, G×E analysis will help in understanding the type and size of G×E interactions expected in a given region. The present inventors contemplate that proper selection of hybrids for a particular land base will improve agricultural

potential of certain geographic areas by maximizing the occurrence of crop performance through the use of the environmental classification. In addition, this approach allows the use of statistical and probability based analysis to quantify the risk of product success/failure according to the frequency of environment classes and the relative performance of genotypes within each environment class. This early identification and selection of hybrids would enable seed producers to start seed production and accelerate the development of hybrids in winter nurseries in warmer southern climates.

[0084] Moreover, environmental classification allows for the creation of an environmental profile for all or any part of the land base classified. Environmental classifications can be determined for each producer's land base. Similarly, the environmental performance profile of cultivars/hybrids can be determined through field experimentation or predicted using G×E analysis. In combining environmental classification frequencies for a particular land base and product performance by environmental classification, performance measurements are given the appropriate amount of relevance or weight for the land base in question. For example, the data are weighted based on long-term frequencies to compute a prediction of hybrid performance.

Use of G×E in Producer's Selection

[0085] According to another aspect of the present invention, a method of using information that documents the environmental profile over time of a crop producer's land base, the environmental performance profile of crop cultivars, and the producer's objectives to select a portfolio of cultivars that maximizes and quantifies the probability that the producer's objectives for productivity will be met. Environmental classification can be used to assist in this process.

[0086] Environmental classification can be used to determine the primary environmental drivers of G×E interaction in crops such as corn. That is, what are the primary environmental factors that cause change in the relative performance of hybrids. With this knowledge, crop production areas can be categorized into environmental frequency classes. Within these classes, hybrids tend to perform (as measured by yield) relatively similar to one another. Across these classes, the relative performance of hybrids tends to be significantly different. Using historical meteorological information along with soils, pests, and other agronomic information, the frequency of these environments can be determined. This allows the creation of an environmental profile for all or any part of the geography classified. That is, a frequency distribution of the occurrence of the key Environment Classes. This can be done for each crop producer's land base.

[0087] Similarly, the environmental performance profile of crop cultivars can be determined through field experimentation. That is, a description of relative performance of cultivars can be determined in each of the key environment classes. In combining Environment class frequencies for a particular land area and product performance by Environment Class, performance measurements are given an appropriate amount of relevance or weight for the land area in question. Thus, this aspect of the invention involves combining of this information at the producer's level to optimize crop productivity in such a way that it maximizes the

probability of the producer's business operation reaching its productivity goals. The present invention contemplates that information can be used from any number of classification schemes to the selection of cultivars with the objective of maximizing the probability of attainment of the productivity and business goals of a crop producer's operation.

[0088] The approach of this aspect of the present invention does so by using compiled long term geo-referenced weather, soils, and agronomic data including biotic factors for the producer's land base to categorize the land base in terms of how frequently annual environmental variation occurs to a degree that is likely to impact relative hybrid performance. In addition, it can incorporate the producer's business objectives including, but not limited to preparedness to take risk. The present invention is able to combine environmental variability with producer business information to create a producer profile. Product performance information stratified by the same criteria is used to define the producer's environmental profile (for example, environmental classes) which is then integrated with the producer's profile.

[0089] The relative hybrid performance information that is relevant to the producer's land base is used regardless of when and where it was generated. The present inventors are first to predict future performance of genotypes and quantify probability/risk associated with that performance using data from environments that are considered to be substantially equivalent in terms of relative hybrid response. The result is a more robust and predictive data set thus allowing more informed product selection decisions that, over time will result in a higher probability of a producer operation meeting business objectives for productivity.

[0090] FIG. 9 illustrates information flow according to one embodiment of the present invention. In FIG. 9 there is an environmental profile 100. The environmental profile can be based on one or more inputs such as environment classes 102, meteorological information 104, agronomic information 106, or field experimentation 108. In FIG. 1 there is also a producer profile 110. The producer profile 110 is based on one or more inputs such as risk tolerance 112 of the producer, business goals 114 of the producer, productivity goals 116, financing 118 considerations, third party needs 119, for example a landlord, or insurance/risk management and marketing 120 considerations. The environmental profile 100 and the producer profile 110 are combined in order to produce recommendations 122. The recommendations 122 can include risk management tools, a recommended seed product, a recommended mix of seed products, production practice recommendations, such as chemical application information, or any number of other specific recommendations as may be appropriate based on the particular environmental profile 100 and producer profile 110.

[0091] FIG. 10 illustrates one embodiment of a system 124 for producing product recommendations. In FIG. 9, a processor 126 accesses information associated with a producer profile 110, an environmental profile 100, and a genotype by environment database 132. There is an input device 128, a recommendation output 129, and a display 130 operatively connected to the processor. The present invention contemplates that the processor 126 can be associated with a computer such as handheld computer as may be convenient for a dealer or sales agent. The present invention

also contemplates that the producer profile 110, environmental profile 100, and genotype by environment database 132 may be accessible over a network, including a wide-area network such as the Internet.

[0092] Using the information in the producer profile 110, environmental profile 100, and genotype-by-environment database 132, the processor applies one or more of a product selection algorithm module 134, a product comparator 136, a production practice module and a risk comparator 138, and a product portfolio module 140. These and/or other modules are collectively the recommendation logic 142. In a simple case, the product selection algorithm module 134 would take information from the environmental profile 100, such as an environmental classification ("Temperate", for example) in addition to information from the producer profile 110, such as a producer objective ("Maximize Yield", "Risk Minimization", "Low Harvest Moisture" for example) and match these criteria to products in the genotype-by-environment database 132. Of course, more specific criteria could be examined as would be the case with more complex environmental profile information and more complex producer profile information.

[0093] FIG. 10 illustrates one embodiment of a screen display 144 of a software application the present invention. In FIG. 10, a user is given the choice of selecting "DEFINE ENVIRONMENTAL PROFILE" 146, "DEFINE PRODUCER PROFILE" 148, and "VIEW RECOMMENDATIONS" 150. Of course, the present invention contemplates that software and its accompanying user interface can be implemented in any number of ways.

[0094] FIG. 11 illustrates one embodiment of a screen display 152 of a software application of the present invention. In FIG. 11, a recommendation is given which includes a plurality of products 154, an associated number of acres 156 associated with each of the products, a risk/probability assessment 157, and a recommended crop revenue assurance 158. The present invention provides for decreasing the amount of risk associated with selection of a particular seed product by instead selecting multiple products with different GxE interactions in order to reduce risk associated with environmental variations. The resulting selection, is somewhat akin to selection of stocks in a stock portfolio.

[0095] FIG. 12 and FIG. 13 illustrate embodiments of user interfaces to use in precision farming applications. In FIG. 12, the user interface 170 includes site-specific information associated with location information 172. The present invention contemplates that other site-specific information or historical information is accessible based on the location information 172 and may be used in product selections. In addition, environment and production information is collected. Examples of such information includes maturity days 176, input traits 178, output traits 180, seed treatment 182, whether no till practices 174 are used, the planting population 184, nitrogen utilization 186, and drought impact based on environmental classification drought frequency information 187 and soil type. Based on this information and information associated with the location 172, a recommendation 188 of at least one hybrid seed product is made. Where multiple recommendations are made, the recommendations can be ranked as well as a risk assessment 189-such as shown.

[0096] **FIG. 13** illustrates another embodiment of a user interface **200** that can be used in crop production applications. Site specific information is collected such as location **172**, soil type **174**, and number of acres **202**. In addition, there is the option to import precision farming data **204** as well as import environment of frequency data **205**. There are also the options to set production practices, set environmental assumptions, set risk levels, and set the maximum number of hybrids **212**. Based on the inputs, a portfolio is created that includes a plurality of products **214**, an associated number of acres **216** to plant for each product, a recommendation **217** of at least one hybrid seed product, a risk assessment **218**, and revenue assurance **219**. Where multiple recommendations are made, the recommendations can be ranked. There is also an option to generate precision farming information **220** based on this information, such as a prescription map. The present invention contemplates that the precision farming information may indicate which acres to plant with which hybrids, give specific production practice application (such as chemical application rates), or other recommendations.

[0097] **FIG. 14** illustrates one example of a field-by-field analysis showing product recommendations for a land base of a producer. As shown in **FIG. 14**, different land areas within a producer's land base have different hybrids associated with them. The present invention contemplates producing such a map or field-by-field recommendations where multiple products are recommended. It should further be understood that a single producer or other user may have operations in a number of geographically diverse locations, and not necessarily the nearby fields illustrated in **FIG. 14**.

[0098] It should also be appreciated that the use of environmental classification and G x E interactions should be effectively communicated to customers. The effectiveness of the environmental classification process is based in part on its ability to use historical data from many locations so that all available data is used. This aspect of environmental classification would seem counter-intuitive to a customer who primarily relies upon personal knowledge in the local area. The customer's confidence in firsthand production knowledge can be used to assist in increasing confidence in environmental classification.

[0099] **FIG. 15** illustrates one example of the methodology of this aspect of the invention to assist in explaining these concepts to a producer. In step **300** site-specific data collection for a land base is performed. Based on this site-specific data collection, in step **302**, the land base is given an environmental classification. In addition to this information, the type of hybrid selected in the previous year and its performance is provided by the producer in step **304**. In step **306**, a prediction is made as to the previous year's production based on environmental classification. In step **308**, the predicted results are compared with the actual results. The present invention also contemplates not requiring performance results from the producer until after the previous year's results have been predicted in case the producer is not confident that an independent prediction is made.

[0100] **FIG. 16** illustrates one example of a screen display showing such comparisons. In **FIG. 16**, performance predictions (yield) are made for a number of different hybrids for both the previous year and the current year. In addition,

a risk assessment for each hybrid may also be provided. The producer can compare the prediction for the previous year with the actual performance for that year in order to understand how well the environmental classification method can predict a result. If the producer is confident in the method's ability to correctly predict a result, the producer will be more inclined to use the prediction made for the coming year. The present invention contemplates that the same or similar information can be presented in any number of ways. It should further be understood that such a demonstrate assists in illustrating the accuracy of the system in predicting relative performance differences between seed products. Due to the number of potential variables and difficulty in controlling such variable accurate prediction of absolute performance is generally not a reasonable goal. However by selecting appropriate environmental classifications, useful insight into relative performance can be provided.

Precision Agriculture and Environmental Classification

[0101] Precision farming or site specific farming recognizes that increased information and precise control over crop production processes can result in more efficient use of resources. The use of Global Positioning System (GPS) and variable rates of production inputs and outputs are often closely associated with precision farming. Concepts in precision farming recognize variations throughout a land base, including throughout the same field. Variability can include variable outputs (i.e. yield) as well as variability in inputs obtained from the farmer (i.e. seeds, chemicals, etc.) as well as variations in the soil properties or variations in other environmental characteristics. Thus, examples of site specific data can include data relating to soil type, soil pH, irrigation related information, tiled area information, previous crop information, fertilizer including nitrogen, phosphorous, and potassium levels, insecticide, herbicide, and biotic data, drainage topography (soil moisture and stresses), crop variety (disease resistance, root systems, ability to adapt to extreme conditions), insect or weed information, crop rotation information, tillage practices (type, timing, wet/dry soil), compaction, pH (extreme pH variability (<5.5 or >7.5), herbicides (misapplication, drift, phytotoxic effects), subsoil condition (acid or alkaline subsoil, clay layer, fragipan, etc), fertility placement (ridge-till, no-till, etc), fertility level, plant population, etc.

[0102] Some agricultural enterprises have historic information which may include soil information, yield information, chemical application information and other types of information that may be associated with or collected through precision farming techniques. This information is usually geo-referenced with GPS information.

[0103] The present invention allows for information obtained directly from a customer such as a crop producer to be used in conjunction with environmental classification information to predict performance of seed products under various combinations of conditions. Moreover, the present invention provides for specific recommendations of seed products or combinations of seed products for the crop producer to reduce risk. These recommendations are also not necessarily limited to the selection of seed products but also recommendations regarding other crop management selections including use of particular chemicals.

[0104] The use of precision agriculture-type information is advantageous as this additional information enhances

historical data and can improve future predictions of appropriate products. The use of precision agriculture-type information is also beneficial in building a relationship with producers and in gaining acceptance of the use of environmental classification information and models. In particular, it may seem unintuitive to crop producers to use information from far off locations or otherwise geographically diverse locations in predicting the appropriate products for their use as is preferably performed using environmental classification of the present invention. In fact, use of such information runs completely contrary to the notion of "site specific" farming. The combining of this information with site specific crop producer experienced and/or verified information may assist in crop producer acceptance of the adoption of environmental classification and related products and services.

[0105] The present invention further provides for incorporating the environmental classification information into a crop producer's precision farming program. In particular, high resolution environmental classification could be used to make different selections of seed products and rate of planting for different areas of the same field based on the known variables such as soil properties and accordingly taking into account genetic by environment interaction. Environmental classifications can be taken at different levels. Although a preferred level is the township level, the level may be of a higher resolution including by field or by grid area within a field, and could be incorporated at a higher resolution field, with a preferred level being a township. Planters such as that described in U.S. Pat. No. 5,915,313 to Bender et al, and assigned on its face to Case Corporation, herein incorporated by reference in its entirety, allow for planting multiple types of seeds within the same field in a single pass according to a prescription type map. The environmental classification of the present invention could be used to provide for a means to create such as a prescription type map as it makes available appropriate information about particular seed products and provides an improved perspective on genetic by environment interactions. Where environmental classification using appropriate classes is used, the present invention provides for selecting the appropriate seed product for each grid or location. Thus the environmental classification of the present invention could also be used to assist in precision farming. It should also be understood that the present invention is not limited to making appropriate seed product recommendations, but can also include providing other recommendations as to production practices which may be appropriate based on predicted genotype-by-environment interactions. Examples of other types of recommendations include herbicide, pesticide, fertilizer types, application rate, and application timing, irrigation recommendations, and any number of other recommendations as to the production techniques to be employed.

[0106] FIG. 13 illustrates information flow according to one embodiment of the present invention. Environmental classification information 160 is used to provide genotype-by-environment information and incorporates information that is non site-specific. The environmental classification information 160 could be used in conjunction with precision farming information 162 which is site-specific. In addition site specific environmental information on drought risk, for example, soils, environmental classification, drought frequency, is incorporated. This combination of information is used to provide recommendation information 164. The rec-

ommendation information 164 can take on numerous forms and may include product recommendations as well as production practice recommendations. Examples of such information include prescription maps with different seed products, different seed product recommendations for different land bases, product recommendations with associated risk scenarios and related predictions.

[0107] Information is then obtained based on the planting of the products, preferably based on the product recommendations. This experiential data 166 can then be used to assist in the future development of environmental classification 160 as well as being incorporated into the site specific precision farming information 162.

[0108] Information may also be obtained from the producer to assist an agricultural input supplier in forming environmental classifications for a variety of agricultural inputs. FIG. 17 illustrates information flow according to one embodiment of this invention. Crop producers 230 provide crop production information 232 to agricultural input suppliers 234. The crop production information 232 may include, but is not limited to, seed product information 236, environmental profile information 238, performance information 240, and genotype by environment information 242. While the crop production information may additionally include location information, it is important to note that the crop production information may be provided without the disclosure of location information or producer identity. The crop production information 232 is stored in a data base 242. Utilizing the crop production information 232 stored in the data base 242, an environmental classification 244 can be associated with various agricultural inputs 246. These agricultural inputs may include a land base, regions of a land base, or a seed product.

[0109] FIG. 14 and FIG. 15 illustrate embodiments of user interfaces to use in precision farming applications. In FIG. 14, the user interface 170 includes site-specific information associated with location information 172. The present invention contemplates that other site-specific information or historical information is accessible based on the location information 172 and may be used in product selections. In addition, environment and production information is collected. Examples of such information includes maturity days 176, input traits 178, output traits 180, seed treatment 182, whether no till practices 174 are used, the planting population 184, nitrogen utilization 186, and drought impact based on environmental classification drought frequency information 187 and soil type. Based on this information and information associated with the location 172, a recommendation 188 of at least one hybrid seed product is made. Where multiple recommendations are made, the recommendations can be ranked as well as a risk assessment 189-such as shown.

[0110] FIG. 15 illustrates another embodiment of a user interface 200 that can be used in precision farming applications. Site specific information is collected such as location 172, soil type 174, and number of acres 202. In addition, there is the option to import precision farming data 204 as well as import environment of frequency data 205. There are also the option to set production practices, set environmental assumptions, set risk levels, and set the maximum number of hybrids 212. Based on the inputs, a portfolio is created that includes a plurality of products 214, an associated number of

acres **216** to plant for each product, a recommendation **217** of at least one hybrid seed product, a risk assessment **218**, and revenue assurance **219**. Where multiple recommendations are made, the recommendations can be ranked. There is also an option to generate precision farming information **220** based on this information, such as a prescription map. The present invention contemplates that the precision farming information may indicate which acres to plant with which hybrids, give specific production practice application (such as chemical application rates), or other recommendations.

[0111] **FIG. 16** illustrates one example of a field-by-field analysis showing product recommendations for a land base of a producer. As shown in **FIG. 16**, different land areas within a producer's land base have different hybrids associated with them. The present invention contemplates producing such a map or field-by-field recommendations where multiple products are recommended.

[0112] The present invention contemplates numerous variations from the specific embodiments provided herein. These include variations in the environmental classifications, performance characteristics, software or hardware where used and other variations.

[0113] All publications, patents and patent applications mentioned in the specification are indicative of the level of those skilled in the art to which this invention pertains. All such publications, patents and patent applications are incorporated by reference herein for the purpose cited to the same extent as if each was specifically and individually indicated to be incorporated by reference herein.

1. A computer-assisted method of selecting seed products for planting by a crop producer associated with a field, each of the seed products having a genotype, the method comprising:

dividing the field into a plurality of regions;

providing an environmental profile for each of the regions;

determining a recommendation of a seed product for each of the regions based on the environmental profile and performance of the genotype of each of the seed products in the environmental profile of the regions;

providing an output comprising identification of the seed product to plant within each of the regions.

2. The computer-assisted method of claim 1 wherein the environmental profile includes an environmental classification associated with each of the regions.

3. The computer-assisted method of claim 1 wherein the step of determining the recommendation is based at least partially on genotype-by-environment interactions.

4. The computer-assisted method of claim 1 wherein the step of determining the recommendation is based at least partially on genotype-by-environment-by-management interactions.

5. The computer-assisted method of claim 1 wherein the environmental profile includes agronomic information.

6. The computer-assisted method of claim 1 wherein the environmental profile includes data selected from the set consisting of wind data, temperature data, solar radiation data, precipitation data, soil type data, soil pH data, planting and harvesting dates, irrigation data, tiled area data, previous

crop data, fertilizer data, nitrogen level data, phosphorous level data, potassium level data, insecticide data, herbicide data, and biotic data.

7. The computer-assisted method of claim 1 wherein the output is displayed on a display.

8. The computer-assisted method of claim 1 further comprising supplying the seed products.

9. The computer-assisted method of claim 1 further comprising planting the seed products.

10. The computer-assisted method of claim 1 further comprising wherein the output further comprises at least one management recommendation for each of the regions.

11. The computer-assisted method of claim 10 wherein the management recommendation includes herbicide recommendations.

12. The computer-assisted method of claim 10 wherein the management recommendation includes pesticide recommendations.

13. The computer-assisted method of claim 10 wherein the management recommendation includes fertilizer type recommendations.

14. The computer-assisted method of claim 10 wherein the management recommendation includes application rate recommendations.

15. The computer-assisted method of claim 10 wherein the management recommendation includes application timing recommendations.

16. The computer-assisted method of claim 10 wherein the management recommendation includes irrigation recommendations.

17. The computer-assisted method of claim 1 further comprising wherein the output further comprises a prescription map based on the environmental profile for each of the regions.

18. The computer-assisted method of claim 2 wherein the environmental classification is selected from a set of environmental classes, the set of environmental classes comprising a temperate class, a temperate dry class, a temperate humid class, a high latitude class, and a subtropical class.

19. The computer-assisted method of claim 2 wherein the environmental classification is selected from a set of environmental classes, the set of environmental classes comprising biotic classifications.

20. The computer-assisted method of claim 3 wherein the genotype-by-environment interactions are determined at least partially based on performance data associated with the seed products.

21. The computer-assisted method of claim 3 wherein the genotype-by-environment interactions are determined at least partially based on environmental classifications associated with performance data of the seed products.

22. The computer-assisted method of claim 21, wherein said performance data includes at least one item from the set consisting of yield, drought resistance, grain moisture, lodging, stand establishment, emergence, midsilk, test weight, protein, oil, and starch percentage, relative maturity, plant height, seed size, disease resistance genes, heading date, resistance to insects, brittle snap, stalk breakage, resistance to fungus, seed moisture, head shape, hullability, seedling vigor, beginning bloom date, maturity date, seed shatter, winter survival, fiber strength, and color grade.

23. The computer-assisted method of claim 1 wherein the performance is expected performance.

24. The computer-assisted method of claim 1 wherein the performance is actual performance.

25-26. (canceled)

27. A computer-assisted method of selecting seed products for planting by a crop producer associated with a land base, each of the seed products having a genotype, the method comprising:

dividing the land base into a plurality of regions;

classifying each of the regions with an environmental classification;

determining a recommendation of a seed product for each of the regions based on the environmental classification;

providing an output comprising identification of the seed product to plant within each of the regions.

28. The computer-assisted method of claim 27 wherein the output further comprises predicted performance data for the seed product.

29. The computer-assisted method of claim 28 further comprising comparing the predicted performance data to actual data.

30. The computer-assisted method of claim 29 wherein the step of determining a recommendation is based at least partially on genotype-by-environment interactions.

31. The computer-assisted method of claim 27 wherein the step of determining a recommendation is based at least partially on genotype-by-environment-by-management interactions.

32. The computer-assisted method of claim 27 further comprising supplying the seed products.

33. The computer-assisted method of claim 27 further comprising wherein the output further comprises at least one management recommendation for each of the regions.

34. The computer assisted method of claim 27 wherein the recommendation provides for planting a plurality of seed products within the field.

35. The computer assisted method of claim 27 wherein the recommendation provides for planting a single seed product within the field.

36. A method to assist in classifying agricultural inputs, the method comprising:

collecting crop production information from a plurality of crop producers wherein the crop production information comprises type of seed product, environmental profile information, and performance information;

storing the crop production information in a data base;

determining a set of environmental classifications to describe the agricultural inputs at least partially based upon the environmental profile information and performance information.

37. The method of claim 36 wherein the crop production information further comprises genotype-by-environment interactions.

38. The method of claim 36 wherein the agricultural inputs include land base.

39. The method of claim 36 wherein the agricultural inputs include regions of a land base.

40. The method of claim 36 wherein the agricultural inputs include the type of seed product.

41. The method of claim 36 wherein the crop production information further comprises location information.

42. The method of claim 36 further comprising the crop production information excludes location information and producer identity.

43. The method of claim 41 wherein the location information includes historic information.

44. The method of claim 43 wherein the historic information includes soil information data.

45. The method of claim 43 wherein the historic information includes yield information data.

46. The method of claim 43 wherein the historic information includes chemical application information.

47. The method of claim 41 wherein the location information includes environment and production information.

48. The method of claim 47 wherein the environment and production information includes data selected from the set consisting of maturity days, input traits, output traits, seed treatment, no till practice information, planting population, nitrogen utilization, drought impact based on environmental classification, drought frequency information, and soil type.

49. The method of claim 36 wherein the crop production information further comprises genotype-by-environment-by-management interactions

50. The method of claim 36 wherein the environmental profile information includes agronomic information.

51. The method of claim 36 wherein the environmental profile information includes data selected from the set consisting of wind data, temperature data, solar radiation data, precipitation data, soil type data, soil pH data, planting and harvesting dates, irrigation data, tilled area data, previous crop data, fertilizer data, nitrogen level data, phosphorous level data, potassium level data, insecticide data, herbicide data, and biotic data.

52. The method of claim 36 wherein the environmental classifications are selected from a set of environmental classes, the set of environmental classes comprising a temperate class, a temperate dry class, a temperate humid class, a high latitude class, and a subtropical class.

53. The method of claim 36 wherein the environmental classifications are selected from a set of environmental classes, the set of environmental classes comprising biotic classifications.

54. The method of claim 37 wherein the genotype-by-environment interactions are determined at least partially based on performance data associated with the seed products.

55. The method of claim 37 wherein the genotype-by-environment interactions are determined at least partially based on environmental classifications associated with performance data of the seed products.

56. The method of claim 36, wherein the performance information includes at least one item from the set consisting of yield, drought resistance, grain moisture, lodging, stand establishment, emergence, midsilk, test weight, protein, oil, and starch percentage, relative maturity, plant height, seed size, disease resistance genes, heading date, resistance to insects, brittle snap, stalk breakage, resistance to fungus, seed moisture, head shape, hullability, seedling vigor, beginning bloom date, maturity date, seed shatter, winter survival, fiber strength, and color grade.

57. The method of claim 36 wherein the performance information is expected performance information.

58. The method of claim 36 wherein the performance information is actual performance information.

59. The method of claim 36 wherein the crop production information further comprises disease information.

60. The method of claim 36 wherein the crop production information further comprises agricultural pest information.

61. The method of claim 36 wherein determining a set of environmental classifications to describe the agricultural inputs is at least partially based upon the environmental profile information, performance information and location information.

62. A method for making a recommendation for a seed product to plant within a land base, the method comprising:

collecting crop production information from a plurality of crop producers over a plurality of geographically diverse locations;

determining environmental classifications using the crop production information;

classifying the land base with at least one environmental classification;

determining the recommendation for a seed product to plant within the land base based on the at least one environmental classification.

63. The method of claim 62 further comprising supplying the seed product.

64. The method of claim 62, wherein the wherein the crop production information comprises type of seed product, environmental profile information, and performance information.

65. The method of claim 62 wherein the crop production information further comprises genotype-by-environment interactions.

66. The method of claim 62 wherein the land base comprises a plurality of regions.

67. The method of claim 66 wherein each region is classified with an environmental classification.

68. The method of claim 62 further comprising storing the crop production information in a data base.

69. The method of claim 62 further comprising providing an output comprising identification of the seed product to plant within the land base.

70. A method to assist in classifying a seed product, the method comprising:

collecting crop production information from a plurality of crop producers wherein the crop production information comprises type of seed product, environmental profile information, and performance information;

storing the crop production information in a data base;

determining a set of environmental classifications to associate with the seed product at least partially based upon the environmental profile information and performance information.

71. A method to assist in classifying agricultural inputs, the method comprising:

collecting crop production information from a plurality of crop producers wherein the crop production information comprises type of seed product, environmental profile information, performance information and location information;

storing the crop production information in a data base;

determining a set of environmental classifications to associate with the agricultural inputs at least partially based upon the environmental profile information and performance information;

using the set of environmental classifications associated with the agricultural inputs to recommend a subset of the agricultural inputs.

72. The computer assisted method of claim 1 wherein the recommendation provides for planting a plurality of seed products within the field.

73. The computer assisted method of claim 1 wherein the recommendation provides for planting a single seed product within the field.

74. The computer-assisted method of claim 1 further comprising determining an overall environmental profile for the field based on the environmental profile for each of the regions.

75. The computer-assisted method of claim 74 wherein the environmental profile includes an environmental classification associated with each of the regions.

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