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Geographic screening of potential alternative crops

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Abstract

Alternative crops, with appropriate markets and infrastructure, provide farmers the potential for diversification to offset financial stress caused by an overabundant supply of a limited number of species grown over a broad area. The objective of this work was to develop a model that would identify where soil and climate conditions are likely to be suitable for a large number of crops over a large geographic region. The model was used to screen 414 crops for suitability to Illinois conditions. The 414 crops were a subset of 968 candidate crops, for which crop soil (texture, pH, drainage) and climate (temperature, precipitation, growing season length, minimum winter temperature) requirements were identified from a literature search. The simple model was linked to geographic information system software to evaluate the suitability of the soil and climate conditions of Illinois. Two of the 414 crops were classified as highly suitable in more than 50% of the state's land area, 18 suitable in more than 90% of the state, and a total of 83 crops were rated as suitable to highly suitable in more than 90% of the state. Comparison of the suitability maps to known ranges of existing crops, and limited evaluation of 15 crops classified as suitable, moderately suitable and unsuitable for Urbana, Illinois conditions in a demonstration plot, showed this model's utility to a limited area, and suggests that the model can be applied to any region where geographically referenced soil and climate data either exist or can be developed.

Key words: alternative crops, crop suitability, climate suitability, soil suitability, geographic information systems

Introduction

Each year producers decide which crops to grow, based on their experiences and expectations. Producers consider crops that are well adapted to their climate and soil, can be successfully managed and marketed, and/or they are comfortable growing. Economic pressure increases as the annual world supply of a few widely grown crops, such as corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merrill] and wheat (*Triticum aestivum* L.), exceeds the annual demand. This economic pressure forces producers to either become more efficient or to diversify. Diversification can be achieved by including animal husbandry into farming systems and/or by growing alternative or specialty crops.

Potential alternative crops can be identified from various sources[1–3]. The ultimate selection and adoption of an alternative crop begins with the identification of crops that are suited to local soil and climate conditions. Consideration may also be given to how conditions compare to those of other regions. Once a potential alternative crop has been identified for a region, agronomic and economic studies are needed to improve a crop's probability of success by developing optimal production procedures, improving the genetics of the species, and developing the production infrastructure and markets for the new crop.

While many studies have been valuable in identifying potential alternative crops, few have used geospatial analysis to link requirements for optimum growth of a crop species with soil and climate conditions, to identify regions or areas where specific alternative (non-traditional) crops may be adapted. Therefore, producers must rely on other evaluation methods, such as demonstration plots at various locations. Associated with this is uncertainty about the similarity of soils and climate of the demonstration and the producer's location. This uncertainty has been reduced in some instances with geographic information system (GIS) tools coupled with simple models of crop environment and soil conditions[4–6]. Brooker and Gray[4] and Young et al.[6] used historical climate data in their analyses, while Myers[5] based his analysis on the similarities of the

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alternative crops to traditional crops being grown in the region. The soil information used by Booker and Gray[4] included soil type and slope. Rather than using existing soils information, Young et al.[6] simulated soil data from surficial and bedrock geology and elevation. These simulations provided a detailed soil analysis based on the physiographic features of the region. Myers[5] analyzed the entire state of Missouri, while Brooker and Gray[4] and Young et al.[6] analyzed small regions within the states of Tennessee and Wyoming, respectively.

The objectives of this project were to: (1) identify the soil and climate requirements and their ecological thresholds for as many crops as possible; and (2) develop general growth suitability maps using geographically referenced climate and soils information and a simple agroecological model to relate the different soil and climate requirements of the crops to Illinois conditions. Information about alternative crop soil and climate requirements, and how they match conditions throughout a region, would assist growers when considering diversification of their operations.

Methods

The names of potential and existing cereal, vegetable, animal feed, fiber, timber, energy, fruit, nut, medicinal, and biomass crops were obtained by searching the literature that listed crop species[2,7–19]. While a diverse collection of native and exotic plants was included in the list of potential crops, strictly ornamental crops were excluded. Established crops were included to provide a collection of potential crops with known adaptation for model validation, and insight into where new crops with similar but incomplete agroecological requirements might grow.

A range of information was collected for each crop. Family, genus, species, subspecies classification, botanic synonyms and common names were found for each crop. Notes concerning economic use, geographic distribution[17], climatic zone adaptation[20], woodiness, weediness[21], growth habit (life cycle), photoperiod sensitivity, and light requirement were collected. Additionally, the disease susceptibility of each crop to pathogens endemic to Illinois was assessed (Wayne Pedersen, personal communication). This information was archived in a Microsoft ACCESS database[22].

Often species information is insufficient to identify a specific crop. Therefore, crops were also identified by their economic use and abiotic requirements. In some cases more than one crop may be recognized within the same species, for example both soft red winter wheat and soft red spring wheat are classified as *Triticum aestivum* L. Despite being placed in the same genus and species, they were considered distinct crops in this study because they are adapted to significantly different environmental conditions and have unique uses.

All crops were screened carefully to resolve any scientific name conflicts. Where more than one scientific or common name was identified for each crop, the scientific name from Wiersema and Leon[17] was used to identify the crop.

Climate and soil requirements were collected for as many of the identified crops as possible. The climate requirements included temperature and annual rainfall. Temperature requirements included the four cardinal temperatures, cold tolerance, and length of growing season[23]. Soil properties related to plant adaptation included texture, pH and drainage. These requirements and soil and climate data were used to develop a simple agroecological model coupled to GIS tools to relate crop requirements to Illinois conditions[23].

Inputs to the simple agroecological model included the crop climate and soil requirements, temperature and precipitation data computed from the climate record for 1971–2000, and soils data from the STATSGO database[24]. A detailed description of the agroecological model, with its underlying assumptions and limitations, is available in Bowen and Hollinger[23].

Overall suitability maps for each of the crop soil and climate requirements were created. Five categories of suitability were used: unsuitable (0), slightly suitable (1), moderately suitable (2), suitable (3) and highly suitable (4). The number following the class description is the individual climate or soil property score used in computing the overall suitability. The agroecological model computes, for each county-STATSGO polygon in Illinois, the suitability of temperature, soil pH, soil texture, soil drainage, annual precipitation, growing season length and extreme minimum winter temperature for each crop. These are combined using map algebra[25]. The temperature suitability score, which represents the temperature environment of the region with a single score for the year, is added to the soil pH, texture and drainage scores, and divided by four. The underlying assumption being that these four ecological variables are additive in determining the suitability of a region. Precipitation, growing season length and extreme minimum winter temperature are assumed to follow the law of the minimum. These three scores are multiplied together and divided by 64 to get a value between 0 and 1, and then multiplied to the average of the temperature and soil properties scores. The result is that if either precipitation, growing season length or extreme minimum winter temperature is zero, the location is unsuitable for the crop. The GIS[25] suitability maps were linked to databases through a Web page, designed to allow visualization of the suitability for a selected crop and all data associated with that crop.

Results

The suitability maps are available on the Alternative Crops Suitability Map web site (http:///sws.uiuc.edu/data/altcrops/). There are three methods on this site for identifying crops suitable to Illinois conditions. The most interactive method is the selection of a site from an Illinois map by zooming into a specific county and STATSGO soil map unit. After selecting the location of interest, crops can be selected

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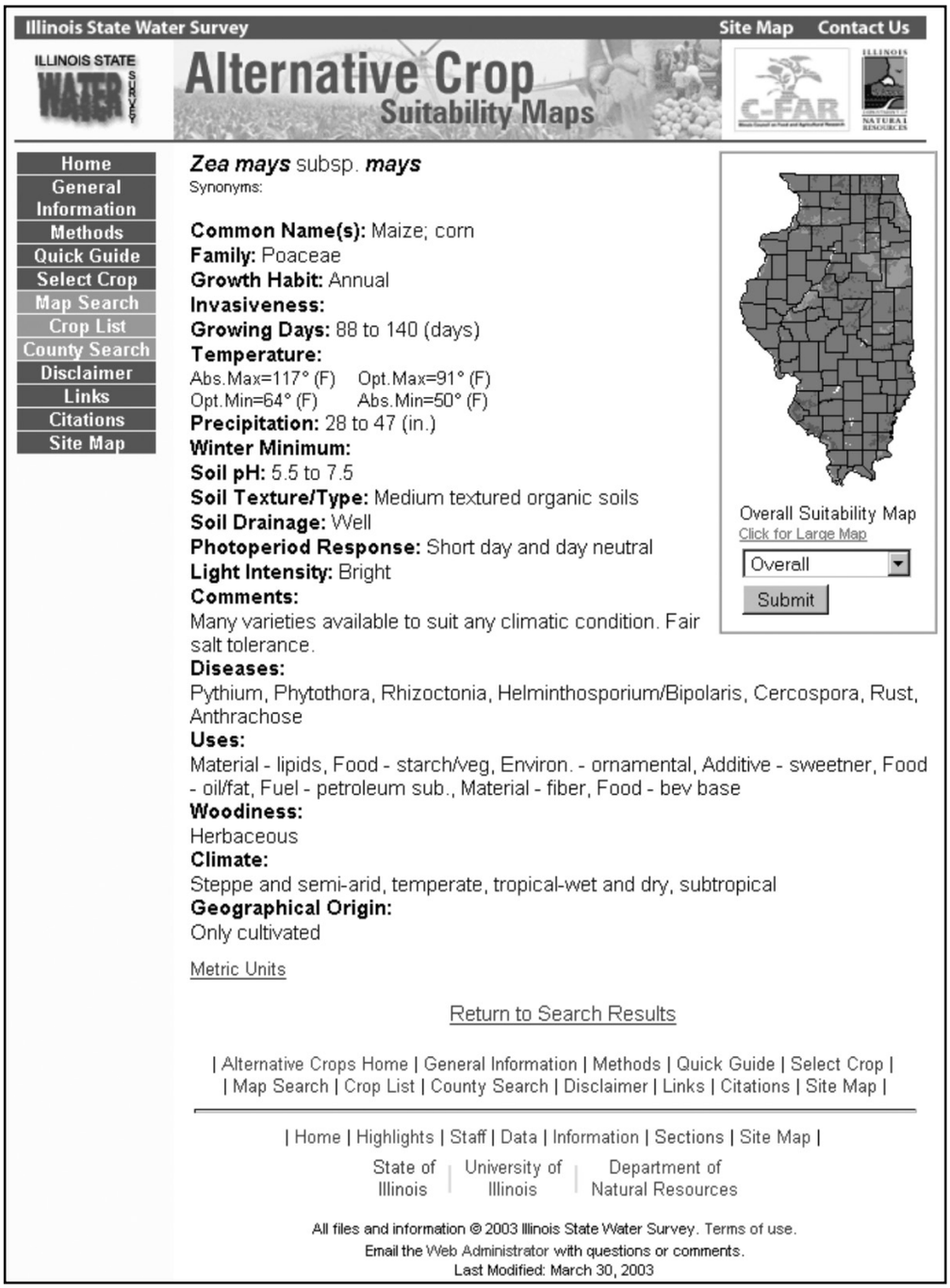


Figure 1. Example of a crop data page from the Alternative Crops Suitability Maps web site showing the information for *Zea mays* subsp. *mays*.

based on suitability classification. For example, if highly suitable crops are selected, only the highly suitable crops for the location will be displayed. If both the highly suitable and suitable classifications are selected, a crop list will be provided showing all highly suitable and suitable crops. The second method is by selection of the county of interest. After a county is selected, a list of crops that fit a specified suitability category is displayed for that county. The third method available is the selection of a specific crop by either scientific or common name. In the last case the crop display page will immediately appear with the crop information and suitability maps if any are available. Selection of the crop by name allows the user to view the available information for all 968 crops in the database.

The crop display page (Fig. 1) displays suitability maps and the information on each crop that is available from the

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database. If an overall suitability map is available, the overall suitability map and each component suitability map can be viewed. If an overall suitability map for a crop is not available, a blank map of the state will be shown, with the statement 'No overall suitability maps available'. However, if there are component suitability maps available, these will be listed on the map and these component suitability maps can then be viewed. For example, suitability maps for balsam fir [*Abies balsemea* (L.) Mill] are available for soil texture, pH, drainage precipitation, growing days and extreme minimum winter temperature. However, the required cardinal temperatures for growth were not available, so a map of temperature suitability and an overall suitability map are not available. Another example is prairie acacia [*Acacia angustissima* (Mill.) Kuntze] for which no suitability maps are available; however, information on diseases, uses, geographical origin and comments about where it is found in the United States are provided. Finally, corn (*Zea mays* L.) is an example of a crop for which data for all the information fields, except invasiveness, are available.

An advanced search feature, available in all crop selection modes, allows the user to narrow the search criteria or describe the location. For example, if only grasses are of interest, the search can be limited to grass crops. The user can also select a broad soil texture class, drainage requirements, soil pH, precipitation range, extreme minimum temperature and growing days to screen the crops. This advanced feature allows the database to be used for conditions throughout the world. Even if the specified conditions are not found in the Illinois, crops that meet the selection criteria can be viewed, although the state map would indicate that the crop is not suitable for Illinois conditions.

Information displayed in the text on the crop page includes scientific and common names, the family of the species, growth habit, invasiveness, growing day requirements, cardinal temperatures, precipitation requirement, minimum winter temperature tolerance, soil pH, texture and drainage requirements, photoperiod response, light intensity preferred, miscellaneous comments about the crop, common diseases to which the crop is susceptible, uses of the crop, woodiness, climate where the crop is generally found, and the geographical origin of the crop. Invasiveness is an indication of the potential for the crop to be a weed. When a crop is also a noxious weed, a list of the states classifying the crop as a noxious weed is provided. The photoperiod response, light intensity preferred, disease susceptibility, the climate where the crop is generally found and the geographical origin are provided, but were not used in determining the crop suitability. Woodiness indicates whether the crop is herbaceous or woody. If no data are available for a specific characteristic, the area where the information would be displayed is left blank. Climate data, temperatures and precipitation may be viewed in either Imperial or SI (international system) units.

While partial or complete information for a total of 968 crops is included in the plant database, only 414 crops had sufficient climate and soil information necessary to run the agroecology model. Therefore, only 414 crops have overall suitability maps. Including the 554 crops without the required climate and soil information in the database allows for easy update of the database and suitability maps as new information for these crops becomes available. The remaining discussion will be limited to those 414 crops for which overall suitability maps are available.

Table 1. Growth habit for the 414 crops with overall suitability maps.

Growth habit	Crops with overall suitability maps
Annual	137
Biennial	4
Biennial/perennial	8
Functional annual	48
Perennial	200
Winter annual	17

Annuals require 1 year to complete a life cycle. Functional annuals are species that require 2 or more years to complete a life cycle but will produce a marketable crop in 1 year. Winter annuals are planted in the fall and harvested the following spring or summer.

The term 'growth habit' defines how a species completes its life cycle. Annual species complete their life cycle in 1 year. Functional annuals are species classified as biennial or perennial, but either produce a marketable product after a single growing year, or must be planted each season because they cannot survive the winter season. For example, tomato (*Lycopersicon esculentum* Mill., var. *esculentum*) is a perennial in tropical regions but is grown as an annual in temperate climates. Of the 414 crops with overall suitability maps, the growth habit of 337 was either perennial or annual, and 17 were winter annuals (Table 1). The growth habits of the remaining crops were either biennial or biennial/perennial species grown as annuals in Illinois conditions.

The crops were classified into six general-use categories: human food, animal feed, potential medicinal (folklore medicinal, pesticide or poison), materials, environmental uses (cover crops, ornamentals, erosion control, etc.) and fuel (Table 2). Unlike growth habit, which is generally unique to each crop, a crop may have several uses. On average, each crop can be used for 2.6 purposes, therefore the total number of uses exceeds the number of crops. Of the 414 crops that have overall suitability maps, 259 can be used as food, 201 as animal feed, 143 as medicines, pesticides or poisons, 105 as materials, 211 for environmental purposes and 35 as fuel.

Suitability maps

Overall suitability maps are available only for those crops in the database with all three soil and all four climate requirements. Of the 414 crops that have overall suitability maps, 309 of those crops had a suitability score greater

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Table 2. Use and growth habit for the 414 crops with overall suitability maps. On average, each crop has 2.6 uses, therefore the total number of growth habit–use combinations will exceed 414.

Growth habit	Food	Animal feed	Medicinal pesticide or poison	Materials	Environmental	Fuel
Annual	99	78	50	28	64	5
Biennial	2	2	4	–	4	–
Biennial/perennial	7	1	5	2	5	–
Functional annual	39	12	19	11	14	1
Perennial	102	93	52	59	120	28
Winter annual	10	15	13	5	4	1

Table 3. Number of crops in each suitability class occupied by the specified percent of the state's land area.

Percent of polygons	Unsuitable	Slightly suitable	Moderately suitable	Suitable	Highly suitable	Suitable and highly suitable
<10	270	396	206	149	374	149
10–25	12	13	61	37	23	37
25–50	7	2	64	33	15	30
50–75	9	3	48	79	2	57
75–90	5	0	32	98	0	58
>90	111	0	3	18	0	83

than 0 (i.e., either slightly suitable, moderately suitable, suitable, or highly suitable) in at least one Illinois county-soil map unit. In all, 111 crops were classified as unsuitable on more than 90% of the state's land area (Table 3). Only two crops were classified as highly suitable on more than 50% of the state's land area, while 18 crops were classified as suitable on more than 90% of the state's land area (Table 3). The two highly suitable crops are perennial grasses which may become weeds (Table 4). Eight of the 18 suitable crops (Table 4) are horticultural crops and are often grown in gardens throughout the state. The remaining suitable crops are mostly grasses used as animal feed or for erosion control.

Crops with combined highly suitable and suitable land area equal to or exceeding 90% of the state's land area were identified by adding the percentage of the land area classified as highly suitable to the percentage of land area classified as suitable for each crop. For example, radish (*Raphanus sativus* L. var. *sativus*) was highly suitable on 9% of the state's land area and suitable on 87% of the state's land area, thus the percentages did not meet the arbitrary cutoffs for either the highly suitable or suitable categories, but when added together met the >90% cutoff for the combined category. A total of 83 crops were identified with more than 90% of the state's land area classified as highly suitable and suitable (Table 3).

These 83 crops included 51 true annuals, annual/perennials and functionally annual/biennials. Thirty-seven of the 51 annual crops may be used as human food (Tables 4 and 5), defined as consumption of a part or all of the plant, used as a food flavoring, an additive or a beverage base. Animal feed, as either forage or fodder, is a use of 21 of the crops. At some time during the plant growth cycle, a part of 10 annual crops may be poisonous to mammals. Four of the annual crops have folklore medicinal uses, eight may be used for material purposes, 12 may be used for environmental or ornamental purposes, six are classified as weeds that have the potential to contaminate seeds, and two [*Zea mays* L. subsp. *mays* and *Sesbania cannabina* (Retz.) Pers.] can be used as a fuel. Material uses include essential oils, lipids, resins, gums and fiber used in manufacturing. Environmental uses include ornamentals, and plants for erosion control, revegetation and soil improvers (i.e., green manures).

Thirty-two crops (Tables 4 and 6) are either biennial or perennial plants. The uses of these crops include food (15), animal food (17), medicinal/poison (13), material (3), environmental (19) and weeds (16). One crop, *Miscanthus* × *giganteus* may be used as a fuel. Fifty percent of the biennial/perennial crops have the potential to be weedy or contaminate the seed supply of other crops. This compares to only 12% of the annual crops that are weedy. Conversely, fewer of the biennials/perennials (47% versus 67% of annuals) are used in the human food supply. Those that are used as foods tend to be fruits, i.e., raspberries, and food additives.

Although winter annuals are grown in Illinois and have regions with highly suitable to suitable growing conditions, less than 90% of the land area was classified as highly suitable and suitable. A crop widely grown in Illinois that does not show up on the list is the annual crop, soybean [*Glycine max* (L.) Merr.]. This crop is classified as suitable

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Table 4. Crops classified as either highly suitable on more than 50%, or suitable on more than 90% of the land area of the state.

Scientific name	Common name	Uses	Growth habit[1]	Percent land area
Highly suitable				
Elytrigia repens (L.) Devs. Ex Nevski	Quack grass	Animal food, medicinal, food additive, weed	P	56
Poa trivialis L.	Rough bluegrass, rough stalk meadow grass, bird grass	Ornamental, animal food, weed	P	52
Suitable				
Armoracia rusticana Gaertn. et al.	Horseradish	Food additive, medicinal, poison	A/P	91
Brassica oleracea L. var. *gemmifera* Zenker	Brussels sprouts	Food, poison—mammals	FA/B	96
Capsicum annuum L. var. *annuum*	Green pepper, cayenne pepper	Food, medicinal, poison—mammals	A	91
Capsicum baccatum L. var. *pendulum* (Willd.) Eshbaugh	Peruvian pepper	Food flavoring	A/P	93
Capsicum chinense Jacq.	Habanero pepper	Food flavoring	A/P	93
Capsicum frutescens L.	Hot pepper, red chili pepper	Food flavoring, poison—mammals	A/P	91
Crambe abyssinica Hochst. Ex R. E. Fr.	Crambe	Material, animal food	A	93
Festuca ovina L.	Sheep fescue	Revegetator, erosion control, ornamental, weed	P	95
Fragaria chiloensis (L.) Duchesne	Beach strawberry, sand strawberry	Food, genetic	P	90
Macrotyloma uniflorum (Lam.) Verdc.	Horse gram	Food, animal fodder, soil improver	A	95
Pisum sativum L. supsp. *sativum* var. *sativum*	Garden pea	Food	A	92
Poa bulbosa L.	Bulbous bluegrass	Forage, fodder, erosion control, weed	A	92
Ribes rubum L.	Redcurrant	Food	P	91
Setaria italica (L.) P. Beauv.	Foxtail millet, German millet	Food, feed, fodder, weed	A	91
Sorghum bicolor (L.) Moench	Broomcorn, grain sorghum	Material, ornamental	A	98
Sorghum × *drummondii* (Nees ex Steud.) Millsp. & Chase	Sudan grass	Animal food, weed, poison—mammals	A	95
Triticum turgidum L. subsp. *durum* (Desf.) Husn.	Durum wheat	Food	A	90
Vigna unguiculata (L.) Walp. supsp. *sesquipedalis* (L.) Verdc.	Asparagus bean	Animal food, food	A	95

[1] Growth habit codes: A, annual; B, biennial; FA, functional annual; P, perennial.

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Table 5. Annual crops classified as highly suitable and suitable, and together occupying more than 90% of the land area of the state. The 14 annual crops listed in Table 4 are also on this list but not repeated in this table.

Scientific name	Common name	Uses	Percent land area
Brassica napus L. var. *napus*	Spring canola	Animal food, food	96
Brassica nigra (L.) W.D.J. Koch	Black mustard	Food flavoring, medicinal, poison	92
Brassica oleracea L. var. *gongyloides* L.	Kohlrabi	Food	93
Cannabis sativa L. subsp. *indica* (Lam.) E. Small & Cronquist	Marijuana	Medicinal, poison	97
Cannabis sativa L. subsp. *sativa*	Hemp	Material, food flavoring	97
Capsicum annuum L. var. *glabriusculum* (Dunal) Heiser & Pickersgill	Bird pepper	Food flavoring, genetic	97
Capsicum pubescens Ruiz & Pav.	Rocoto	Food	98
Chenopodium album L.	Lamb's quarter	Food, weed, poison	99
Chenopodium quinoa Willd. subsp. quinoa	Quinoa	Food, crop disease host	96
Cicer arietinum L.	Chick pea, garbanzo	Food	94
Coriandrum sativum L.	Cilantro, coriander	Materials—oil, food flavoring, medicinal	98
Cucurbita moschata (Duchesne ex Lam.) Duchesne ex Poir.	Butternut squash	Food	92
Cucurbita pepo L. subsp. *ovifera* (L.) D.S. Decker var. ovifera (L.) Harz	Acorn squash, ornamental gourd, summer squash	Food, ornamental	93
Cucurbita pepo L. subsp. *pepo* var. *pepo*	Pumpkin, ornamental gourd, zucchini	Food, ornamental	93
Daucus carota L. subsp. *sativus* (Hoffm.) Arcang.	Carrot	Food, material—lipids, poison	95
Echinochloa colona (L.) Link	Jungle rice	Animal food, weed	93
Echinochloa esculenta (A. Braun) H. Scholz	Japanese millet	Animal food, food	93
Echinochloa frumentacea Link	Indian barnyard millet	Animal food	96
Guizotia abyssinica (L. f.) Cass.	Niger seed		94
Kummerowia striata (Thunb.) Schindl.	Common lespedeza	Animal food, weed, erosion control	99
Lens culinaris Medik. subsp. *culinaris*	Lentil	Food, soil improver, animal food	98
Medicago lupulina L.	Black medic, yellow trefoil	Animal food, weed, honey, environmental	98
Medicago scutellata (L.) Mill.	Snail medic	Animal food	97
Origanum majorana L.	Sweet marjoram	Food flavoring, material—oils	94
Papaver somniferum L. subsp. *somniferum*	Opium poppy	Food, animal food, ornamental	95
Phaseolus coccineus L. subsp. *coccineus*	Ayocote, scarlet runner bean	Food, ornamental	94
Phaseolus vulgaris L. var. *vulgaris*	Green bean, beans in general	Food, animal food	93
Raphanus sativus L. var. *sativus*	Radish	Food	96
Sesbania cannabina (Retz.) Pers.	Canicha	Material—gum/resin/fiber, fuel, animal food, soil improver	90
Trifolium alexandrinum L.	Berseem clover, Egyptian clover	Animal food	97
Triticum aestivum L. subsp. *aestivum*	Soft red spring wheat	Food	90
Triticum aestivum L. subsp. *aestivum*	White spring wheat	Food	90
Vicia ervilia (L.) Willd.	Bitter vetch	Soil improver, poison, animal food	95
Vicia villosa Roth subsp. *varia* (Host) Corb.	Woollypod vetch	Poison, animal food	97
Vigna unguiculata (L.) Walp. subsp. *unguiculata*	Cowpea, blackeye pea	Animal food, food	91
Zea mays L. subsp. *mays*	Maize, corn	Food, material—lipids/fiber/fuel	93

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Table 6. Biennial and perennial crops classified as highly suitable and suitable, and together occupying more than 90% of the land area of the state. The six perennial crops listed in Table 4 are also on this list but not repeated in this table.

Scientific name	Common name	Uses	Percent land area
Acer saccharum Marshall subsp. *saccharum*	Sugar maple	Food, ornamental, material	97
Agrostis gigantean Roth	Redtop	Animal food, erosion control, poison, weed	97
Alopecurus pratensis L.	Meadow foxtail	Animal food, ornamental, weed, erosion control	93
Andropogon gerardii Vitman	Big bluestem	Animal food, weed, revegetator	97
Astragalus cicer L.	Cicer milk vetch	Honey, animal food, medicinal, erosion control	93
Beckmannia syzigachne (Steud.) Fernald	American slough grass	Animal food, erosion control	94
Bromus inermis Leyss. subsp. *inermis*	Smooth brome, bromegrass	Animal food, weed, poison, erosion control	96
Cichorium intybus L.	Chicory	Weed, poison, food	93
Elymus trachycaulus (Link) Gould ex Shinners subsp. *trachycaulus*	Slender wheatgrass	Animal food, erosion control	93
Festuca pratensis Huds.	Meadow fescue	Weed, animal food, erosion control	93
Levisticum officinale W.D.J. Koch	Lovage	Medicinal, food flavoring	92
Lolium perenne L.	Perennial ryegrass	Ornamental, erosion control, weed, poison, animal food	98
Melilotus albus Medik.	White sweet clover	Honey, animal food, weed, soil improver, poison	96
Melilotus officinalis Lam.	Yellow sweet clover	Honey, weed, animal food, poison	96
Menthe spicata L.	Spearmint	Material—oils, medicinal	97
Miscanthus × *giganteus*	Miscanthus	Environmental, fuel	93
Morus rubra L.	Red mulberry	Food, material—wood	90
Nepeta cataria L.	Catnip	Food flavoring, medicinal, ornamental	94
Pascopyrum smithii (Rydb.) Á. Löve	Western wheatgrass	Revegetator, erosion control, animal food	96
Phleum pretense L.	Timothy	Animal food, poison, weed	98
Poa compressa L.	Canada bluegrass, flattened meadow grass	Weed, erosion control	99
Poa pratensis L.	Kentucky bluegrass	Animal food, weed, ornamental, erosion control	98
Rubus idaeus L.	Red raspberry; European raspberry	Food, medicinal, crop pest host	95
Rubus occidentalis L.	Black raspberry	Food	98
Rubus strigosus Michx.	American red raspberry, red raspberry	Food, ornamental, weed	94
Sambucus nigra L.	Black elder, European elder	Medicinal, poison	93
Trifolium hybridum L.	Aliske clover	Crop pest/disease host, animal food, honey, erosion control, revegetator, poison	91

on approximately 84% of the land area. Soybean was classified as highly suitable on less than 1% of the land area, and moderately suitable on approximately 15% of the land. This would indicate that soybean could be grown on all the Illinois land area; however, there would be areas where it might not perform as well as other areas. In this case the area is located in southern Illinois, where the combined drainage and soil texture limited suitability to the crop.

Durum wheat [*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.], a crop not grown in Illinois, was classified as suitable on 90% of the land area. Based on the identified climate and soil conditions required by durum, the model shows it should grow in Illinois. However, it is unlikely that in Illinois the durum cultivars would have the high protein content typical of the crop grown in North Dakota, where the nights are cool followed by long, warm days without excessive rain. This points out a limitation of the model. The limitation could be overcome by tightening the climate requirements for the species, and identifies an opportunity to improve the tool by introducing more restrictive cultivar climate and soil requirements to further screen crops.

Model validation

The agroecological model was validated by comparing the suitability maps of existing crops with published maps showing where the crops are currently grown, and by planting, at Urbana, Illinois, a selection of crops with different suitability scores on an Elburn silt loam soil (fine-silty, mixed mesic Typic argiudolls). The crops planted included seven species classified as suitable at the location, eight classified as moderately suitable, and one classified as unsuitable. The suitable species included one variety of broomcorn; *Sorghum bicolor* (L.) Moench; three varieties of chick pea/garbanzo bean, *Cicer arietinum* L.; one variety of crambe, *Crambe abyssinica* Hochst.; 16 edible soybean varieties, *Glycine max* (L.) Merr.; two faba bean varieties, *Vicia faba* L. var. *faba;* two lentil varieties, *Lens culinaris* Medik. subsp. *culinaris*; and one nigerseed variety, *Guizotia abyssinica* (L. f.) Cass. The eight species classified as moderately suitable were one variety each of buckwheat, *Fagopyrum esculentum* Moench; castor bean, *Ricinus communis* L.; kenaf, *Hibiscus cannabinus* L.; and white lupin, *Lupinus albus* L.; two varieties each of pearl millet *Pennisetum glaucum* (L.) R. Br.; safflower, *Carthamus tinctorius* L.; and sunflower, *Helianthus annuus* L. The species classified as unsuitable was Asiatic cotton, *Gossypium herbaceum* L. var. *herbaceum*. Except for buckwheat, which was planted on 6 August 2002, the crops were planted on 4 June 2002. Faba beans, lentils, white lupin, safflower and buckwheat were planted in 0.38 m rows, and the other crops in 0.76 m rows. The first frost occurred on 13 October 2002, 130 days after planting.

The crops were observed each week and notes on the vitality of the crop recorded. The 16 crops had various degrees of success, with success defined as being able to grow and produce a mature harvestable product. Two crops, castor bean and cotton, required a long growing season (>140 days) and also required high minimum temperature (>14°C). These crops did not mature. Cotton was not defined as suitable for the location, while castor bean was classified as moderately suitable. Planting cotton earlier would not have improved its chances of success because of its requirement of high minimum temperatures (18°C). Castor bean may have performed better in 2002 if it had been planted earlier, because its critical minimum temperature requirement was 15°C. These failures occurred in a year when the temperatures in June and July were higher than normal. Thus, if the temperatures had been normal, neither cotton nor castor bean would have grown as well as they did in 2002.

Buckwheat, a moderately suitable crop for the location, did not grow well until September, when the temperatures were cooler. It was planted into dry soil, resulting in a poor stand. While the crop was able to survive the high temperatures of August, because of its high maximum temperature limit (40°C), it grew slowly until the maximum daily temperatures dropped below 27°C in September. Even with these problems, it was rated as a successful crop at the location.

With the exception of kenaf, all crops with an optimum maximum temperature less than 30°C were rated as failures in this trial. These crops included faba bean, lentil, nigerseed and chickpea, all classified as suitable for the location, and white lupin classified as moderately suitable. The failure of the crop was due to 22 days with maximum temperatures greater than 32°C in the first 88 days after planting. These crops may have performed better if they had been planted in April, when the chance for high maximum temperatures is lower, or in a year when temperatures were not higher than normal.

Sunflower (*Helianthus annuus* L.), a plant native to North America, was classified as moderately suitable on 36%, suitable on 60%, and highly suitable on approximately 2% of the land area of the state. Examining individual component suitability maps demonstrates areas throughout the state to be less than suitable for soil texture and drainage. The crop's precipitation requirement best matches conditions in northern Illinois, while temperature requirements best match those of southern Illinois. A large area in the southeast of the state is poorly suited to the pH requirements of sunflower. This area largely coincides with the counties where the species has not been collected as a wild plant[26,27].

Discussion and Conclusions

Alternative crops in farming systems have the potential to provide the diversification needed to combat the financial stress caused by an overabundant supply of a limited number of crops grown over a broad area. Selection of these alternative crops is often based on a limited number of crops that have, for one reason or another, made their

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way into an area, either by progressive farmers' experimenting or by university or federal government research. A Web-based tool was designed to screen a large number of potential crops over a large geographic area. The tool has been used to screen 414 crops for suitability to Illinois conditions. Application to this limited area demonstrated the utility of the tool, and suggests that it can be applied to any region where geographically referenced soil and climate data can be developed.

The 414 crops were a subset of 968 candidate crops for which crop soil (texture, pH, drainage) and climate (temperature, precipitation, growing season length, minimum winter temperature) requirements were identified from a literature search. These data and the soil and climate data of Illinois were analyzed by an agroecological model[23] to determine the suitability of each of the 414 crops to a total of 2442 unique county-soil land areas. Of the 414 crops, two were highly suitable on more than 50% of the land area of the state, and 18 suitable on more than 90% of the land area. A total of 83 crops were rated as suitable to highly suitable on more than 90% of the land area.

The crop database included a list of uses for each crop and growth habit. Growth habit classified each crop as annual, biennial, perennial or a combination of these three. Of the 831 crops identified, the majority were annual crops and used for either human food or animal feed. The biennial and perennial crops were mainly used for animal feed or environmental uses, such as soil erosion control, ornamentals or cover crops. The few biennial or perennial crops used for human food were, for the most part, fruit crops or used as food additives.

The invasive nature of each crop was identified. If a crop was identified as a weed in any one of the 50 states of the US, it was noted as a weed on the crop data page. However, weediness of a crop, its ability to escape and grow wild in an area, is dependent upon the suitability of the soil and climate of the location. For example, for any annual crop where the conditions are highly suitable, the crop could become a weed. On the other hand, a perennial plant that grows well during its growing season and produces a harvestable crop might fail to become a weed problem if the extreme winter minimum temperature is unfavorable for its survival. Cultivation of the crop in this case would result in it being treated as a functional annual, requiring it to be planted each year.

The agroecological model used to develop the suitability maps is limited in its application to an indication of where the soil and climate conditions for a crop may be suitable. This does not infer in any way that the crop will be economically viable, or that it will be competitive with other crops grown in the region. Technology and management can greatly improve the probability of growing an economical crop in a cropping system. However, this is also dependent upon the management skills of the producer. Poor management may result in the failure of a crop in the same region where good management results in a viable crop.

Limited validation of the model with a single year's demonstration plot indicates that the suitability classifications for the 16 species grown are reasonable. At the same time, it points out the importance of multi-year demonstration plots, and timely management practices. Some of the crops that were classified as unsuccessful in the plots may have been successful if planted earlier. However, the late planting in 2002 was due to wet soil conditions and, therefore, the yearly weather may affect the success of a crop.

Classification of a crop as suitable or highly suitable for an area indicates that the crop may have a potential for cultivation in the area, and becomes a candidate for future study. Introduction of new crops is a slow process that has to overcome many hurdles. For example, Nafziger[3] listed potential problems for 19 different potential alternative crops for Illinois. In almost every case, a major problem to adopting the crop is the lack of a market, or limited market opportunities. Another common obstacle listed was the lack of varieties. Therefore, once a candidate crop is identified, it may be many years before the crop is ready to be included in a crop rotation. Soybean, for example, was first grown in Midwest demonstration plots in the late 1800s but did not become an important economic crop until the mid-1920s.

The 2002 field experience supports the necessity for agronomic, pathology, economic, and genetic study prior to planting a new crop. As predicted, the edible soybean and broomcorn grew well, but their success in Illinois is uncertain without understanding the economics of marketing these crops. The model suggested chickpea and crambe as suitable crops, but both failed. The viability of these crops could be improved by considering the effect of planting date, fertility, plant density, weed control and row spacing. Considering the ongoing research to identify appropriate nigerseed varieties for Illinois (Winn Phippen, personal communication 2003), the failure of this crop in the field trial accentuates the importance of genetics and plant breeding when selecting a crop for a region.

Any crop identified as suitable for a region will require considerable study and economic development to ensure a substantial demand for any of the products, the development of markets and of processing plants; and genetic and production research to ensure that the crop is economically viable. Further, considerable effort will be needed to incorporate the crop into existing cropping systems in such a way that producers will be willing to expend the effort to adopt the new crop.

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References

1 United States Department of Agriculture, US Army Corp of Engineers, United States Geological Survey 2001. VegSpec. http://ironwood.itc.nrcs.usda.gov/scripts/ndisapi.dll/vegspec21/spgPurpose.

2 Janick, J. 2002. NewCROP: The new Crop Resource Online Program [Online]. Available at Web site http://www.hort.purdue.edu/newcrop/ (verified 10 January 2002).

3 Nafziger, E.D. 2002. Alternative Crops. Illinois Agronomy Handbook, University of Illinois, Urbana, Illinois. p. 60–65.

4 Brooker, J.R. and Gray, M.D. 1990. Identification of vegetables growing in Tennessee from computer generated maps based on geographic information systems. Tennessee Farm and Home Science, Number 153, winter 1990, University of Tennessee Agriculture Experiment Station, Knoxville, TN.

5 Myers, R.L. 1993. Determining amaranth and canola suitability in Missouri through geographic information system analysis. In J. Janick and J.E. Simon (eds). New Crops. John Wiley and Sons, New York.

6 Young, J.A., Vance, G.F., Munn, L.C., Christensen, B.M., and Schaad, M.S. 2000. A geographic information system for identification of potential alternative crops utilizing soil and climate variables in the Bighorn Basin, Wyoming. American Journal of Alternative Agriculture 15:160–170.

7 Martin, J.H. and Leonard, W.H. 1964. Principles of Field Crop Production. The Macmillian Company, New York. p. 1176.

8 Compton, C.C., Magness, J.R., and Markle, G.M. 1971. Food and Feed Crops of the United States [Online]. Interregional Research Project IR-4, IR Bulletin 1 (Bulletin 828 New Jersey Agricultural Experiment Station). Available at Web site http://www.ncg.nrcs.usda.gov/statsgo.html (verified 11 January 2002).

9 Ritchie, G.A. 1979. New Agricultural Crops. The American Association for the Advancement of Science, Washington, DC.

10 Duke, J.A. 1981. Handbook of Legumes of World Economic Importance. Plenum Press, New York.

11 Duke, J.A. 1983. Handbook of Energy Crops [Online]. Available at Web site http://www.newcrop.hort.purdue.edu/newcrop/duke_energy/dukeindex.html (verified 11 January 2002).

12 Chadwick, A.F., Craker, L.E., and Simon, J.E. 1984. Herbs An Indexed Bibliography. Archon Books, Hamden, Conneticut.

13 Sauer, J.D. 1994. Historical Geography of Crop Plants: A Select Roster. CRC Press, Boca Raton, FL. p. 309.

14 Huston, M., Perlack, R.D., and Wright, L. L. 1997. Biomass Fuel From Woody Crops for Electric Power. Winrock International, Arlington, VA. Available at Web site http://www.winrock.org/REEP/Publications/bsrrpt/BSR1.html (verified 10 January 2002).

15 Frame, J., Charlton, J.F.L., and Laidlaw, A.S. 1998. Temperate Forage Legumes. CAB International, Wallingford, UK. p. 327.

16 Garret, P., Petterson, S., and Simon, J.E. 1998. Guide to Herb Varieties [Online]. Available at Web site http://www.hort.purdue.edu/newcrop/med-aro/herbguide1.html (verified 10 January 2002).

17 Wiersema, J.H. and Leon, B. 1999. World Economic Plants: A Standard Reference. CRC Press, Boca Raton, FL. p. 749.

18 Gold, M.V. and Thompson, R.S. 2001. List of Alternative Crops and Enterprises for Small Farm Diversification [Online]. Available at Web site http://www.nal.usda.gov/afsic/AFSIC_pubs/altlist.htm (verified 10 January 2002).

19 Anon. 2002. Alternative Field Crops Handbook. Center for Alternative Plant and Animal Products, Minnesota Extension Service, University of Minnesota, St. Paul, MN.

20 Food and Agriculture Organization of the United Nations 2000. Ecocrop [Online]. Available at Web site http://www.fao.org/ag/AGP/AGPC/doc/GBASE/Genera.htm (verified 18 January 2002).

21 United States Department of Agriculture 2000. Regulated Noxious Weeds State List [Online]. Available at Web site http://www.aphis.usda.gov/npb/statenw.html (verified 10 January 2002).

22 Microsoft Corporation 1999. Microsoft Access 2000. Microsoft Corporation, Redmond, WA.

23 Bowen, C.R. and Hollinger, S.E. 2004. Model to determine suitability of a region for a large number of crops. Available at Web site http://www.sws.uiuc.edu/data/altcrops (verified 21 January 2004).

24 Soil Conservation Service (SCS) 1993. State Soil Geographic Data Base (STATSGO) Data Users Guide. Miscellaneous Publication 1492, US Department of Agriculture, Soil Conservation Service, Fort Worth, TX.

25 Environmental Systems Research Institute (ESRI) 2000. ArcInfo GIS Version 8.1 for Windows. Environmental Systems Research Institute, Redlands, CA.

26 Iverson, L.R., Prasad, A., and Ketzner, D.M. 1997. A summary of the Illinois flora based on the Illinois Plant Information Network. Transactions of the Illinois State Academy of Science 90:41–64.

27 Iverson, L.R., Ketzner, D., and Karnes, J. 1999. Illinois Plant Information Network. Database at http://www.fs.fed.us/ne/delaware/ilpin/ilpin.html. Illinois Natural History Survey and USDA Forest Service (verified 21 January 2004).

https://doi.org/10.1079/RAFS200473 Published online by Cambridge University Press