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Multicriteria decision analysis applied to cover crop species and cultivars selection

Javier Ramírez-García[a], José María Carrillo[a], Magdalena Ruiz[b], María Alonso-Ayuso[a], Miguel Quemada[a,*]

[a] Schoolof Agricultural Engineering, Technical University of Madrid, Ciudad Universitaria s/n, 28040 Madrid, Spain
[b] Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA), Centro Nacional de Recursos Fitogenéticos, Autovía Aragon Km 36, Apdo 1045, Alcalá De Henares 28800, Madrid, Spain

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ABSTRACT

Cover crop selection should be oriented to the achievement of specific agrosystem benefits. The cover crop, catch crop, green manure and fodder uses were identified as possible targets for selection. The objective was to apply multi-criteria decision analysis to evaluate different species (*Hordeum vulgare* L., *Secale cereale* L., ×*Triticosecale* Whim, *Sinapis alba* L., *Vicia sativa* L.) and cultivars according to their suitability to be used as cover crops in each of the uses. A field trial with 20 cultivars of the five species was conducted in Central Spain during two seasons (October–April). Measurements of ground cover, crop biomass, N uptake, N derived from the atmosphere, C/N, dietary fiber content and residue quality were collected. Aggregation of these variables through utility functions allowed ranking species and cultivars for each usage. Grasses were the most suitable for the cover crop, catch crop and fodder uses, while the vetches were the best as green manures. The mustard attained high ranks as cover and catch crop the first season, but the second decayed due to low performance in cold winters. Mustard and vetches obtained worse rankings than grasses as fodder. Hispanic was the most suitable barley cultivar as cover and catch crop, and Albacete as fodder. The triticale Titania attained the highest rank as cover and catch crop and fodder. Vetches Aitana and BGE014897 showed good aptitudes as green manures and catch crops. This analysis allowed comparison among species and cultivars and might provide relevant information for cover crops selection and management.

1. Introduction

Cover crops selection is oriented to the achievement of goals related to the ability of the crops to provide benefits such as the soil erosion control (Bowman et al., 2000), prevention of winter nutrient leaching (Gabriel et al., 2012) and the supply of organic matter to the soil (Kuo et al., 1997) defined as ecosystem services (Diaz et al., 2007). These benefits are required in different combinations and degrees according to the particular needs of the farmer and the agrosystem. We can distinguish between cover crops, catch crops and green manures according to the specific function developed by the culture in the system. Cover crops are mainly introduced to control the soil erosion pursued by water and wind. However, in some countries, they can be also used to increase the water storage and the sowing opportunity (Clark et al., 1997). When sowing catch crops the objective is to absorb in the vegetal biomass a specific compound contained in the soil, so the pollutant effect is controlled. Green manures perform as nutrient source for the following crop. Green manuring commonly involves the introduction of legumes because of their N fixation, accompanied by the recycling of other nutrients absorbed during the green manure growth period. Fodder production is another possible outcome for cover cropping that may result in an economical benefit for the farmer, even larger than the fertilizer savings attributed to green manuring (Gabriel et al., 2013). It should be stressed that one particular cover crop is able to provide more than one function in the system along its cycle. The capability of a specific cover crop to provide the above mentioned benefits will depend on characteristics of its growth pattern, nutrient exchange or residue quality that can be related with quantitative variables and subsequently characterized and compared (Ramírez-García et al. 2012). There are few attempts

Abbreviations: ADF, acid-detergent fiber; AHP, analytic hierarchy process; BM, above-ground biomass; CN, C:N ratio; DFC, dietary fiber content; ELECTR, Elimination and choice translating algorithm; GC, ground cover; L, lignin; MCDA, multicriteria decision analysis; NDF, neutral-detergent fiber; N_{dfa}, N derived from the atmosphere; N_{upt}, N uptake; RQ, residue quality.

* Corresponding author. Tel.: +34 914524900x1654; fax: +34 915449983.
E-mail address: miguel.quemada@upm.es (M. Quemada).

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in the literature to assess the variables that characterize the cover crops features (Bodner et al., 2010) and to orient cover crops' selection to targeted functions (Jannoyer et al., 2011). Thus, methods allowing the comparison of different cover crop species and cultivars according to the ecosystems services provided may be useful for farmers, breeders and researchers.

Multicriteria decision analysis (MCDA) techniques are applied as an aid for the selection of alternatives in the presence of multiple criteria, usually with conflicting objectives (Zeleny, 1982). Taxonomic classifications of MCDA methodologies can be helpful guiding the decision makers when choosing or combining (mixed methods) the available MCDA techniques (Zanakis et al., 1998; Sadok et al., 2008). The MCDA consists, without regard of the particular method applied, in four steps: (i) structuring the hierarchy of the problem, (ii) establishing the aggregation rules, (iii) aggregating the attributes, and (iv) obtaining ordered alternatives (Guitouni and Martel, 1998). In the agricultural context, Rehman and Romero (1993) reviewed the application of MCDA techniques to the management of agricultural systems and since then, they have been applied to a wide range of topics such as the decision making process in water management policy (Gómez-Limón and Berbel, 2000), the evaluation of the sustainability of different agricultural managements (Sadok et al., 2008) or the farm production planning (Ortuño and Vitoriano, 2011). Continuing under the scope of agriculture, only few studies concerning the choice of species or cultivars have been conducted under different MCDA strategies, mainly under discrete outranking methods. The ELECTRE (elimination and choice translating algorithm) method was developed over more than 30 years by Roy (1993)), and applied by Roudeillac et al. (1997) and Diaby et al. (2010) for strawberry and rubber tree varieties selection, respectively. Other authors like Srdjevic et al. (2004) evaluating walnut cultivars, or Li et al. (2011) selecting *Lilium* species and clones, obtained ranked ordinations of the alternatives assessed after applying an analytic hierarchy process (AHP) to both quantitative and qualitative data. Similarly, Pavlovic et al. (2011) used only qualitative attributes to rank a list of hop hybrids through the DEX method, which combines the problem structuration of AHP with elements of expert systems and machine learning. All those studies included the assessment of experts deciding not only the weights of the variables selected, but in some cases also the values of the attributes attained by the alternatives. As the comparison of species and cultivars to act as cover crops involved different combination of attributes, we choose the weighted average approach, which aggregates multiple criteria into overall values by multi-attribute utility functions (Hayashi, 2000). The performance of an alternative (i.e. a cultivar to act as a cover crop) is the result of the weighted sum of the values attained for each attribute. As this is a compensatory method, it is admitted that an absolute compensation between the different attributes can exist. Thus, a good performance on one attribute can easily counterbalance a poor one on another (Guitouni and Martel, 1998). The global performance may be used to make a ranking among all the alternatives.

In this framework, the objective of our study was to evaluate different species (i.e. barley, rye, triticale, mustard and vetch) according to their suitability to be used as cover crops in each of their specific modalities (cover crop, catch crop, green manure and fodder), as well as for selected cultivars of each species by applying a multi-criteria decision analysis. The rankings obtained may allow judging the performance of the attributes selected for the characterization of the crops studied and the aggregation method applied.

2. Materials and methods

The data collection was performed along two seasons (2010/2011 and 2011/2012) between the months of October and April (May) of the following year at the experimental farm of the Technical University of Madrid (Central Spain). The soil was a sandy loam formed by recent alluvial deposits. The pH (1 g soil/2.5 mL H_2O) was 8.57 and had a 2.20% of organic matter and 0.15% of N. Available P content was 60.4 mg/kg and K 520 mg/kg. The location has a Mediterranean semiarid climate with high interannual variability and a mean annual temperature of 14.6 °C. January monthly temperature of 6.1 °C is the lowest while July the highest with 24.8 °C. The average annual rainfall from October to April is 306 mm. Measurements of the main climate variables were recorded throughout the experiment at the field site (Fig. 1).

Twenty cultivars of five different species were sown within a randomized factorial design with three replications. Seven barley (*Hordeum vulgare* L.) cultivars from the Spanish barley core collection (Igartua et al., 1998) were selected based on their good soil coverage characteristics. These barley cultivars were: Albacete, Cierzo, CNE 73, CNE 81, Hispanic, Tardana and Valencia de Alcántara. Four triticale (×*Triticosecale* Whim) cultivars: Forricale, Montijano, Titania and Verato, were selected from GENVCE database, a Spanish group of breeders and researchers working on cereal varieties. The traditional rye (*Secale cereale* L.) cultivar Petkus was also included, as well as the mustard (*Sinapis alba* L. subsp. *mairei* (H. Lindb.) Maire) selected as a cover crop by IFAPA (Andalusia regional research institute) in Southern Spain (Alcántara et al., 2011). Seven vetch (*Vicia sativa* L.) cultivars were selected to assess variability in a legume crop: Aitana, Alcaraz, BGE014897, Castilla, Kira, Prontivesa and Verdor. Most of the vetches were selected based on cultivars commonly used in Spain, except BGE014897, which is an original entry from CNRF (Plant genetic resources center of Spain).

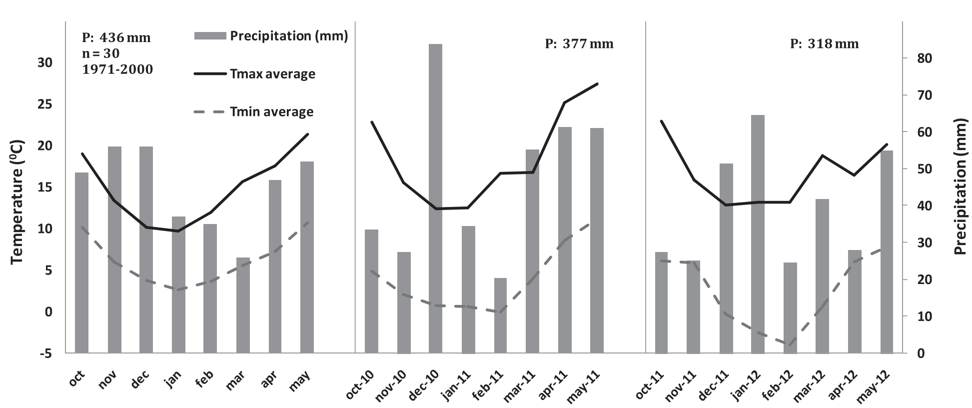

Fig. 1. Climatic data along the growth period of cover crops: (left) 30-year series from a near climatic station; (center) the first (2010–2011) and (right) the second (2011–2012) season of cover crops studies from a climatic station situated at the experimental site.