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Yield performance and stability of dry pea and lentil genotypes in semi-arid cereal dominated cropping systems

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ABSTRACT

The promotion of dry pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) production in cereal dominated cropping systems require identifying high yielding and widely adapted genotypes for a diverse range of environments. However, this information is rarely available in the semi-arid temperate region. We carried out two separate experiments consisting of seven genotypes of dry pea in 25 environments and eight genotypes of lentil in 16 environments to determine yield performance and stability. The results showed that environments (E) and genotypes (G) and interaction (G × E) effects were highly significant ($P < 0.0001$) for both experiments. Average grain yield among genotypes varied from 2243 to 2680 and from 1229 to 1643 kg ha^{-1} for dry pea and lentil, respectively. The G × E accounted 5.4 and 15.8% of the total sum of square for dry pea and lentil experiments, respectively. The G × E effects were crossover type for both experiments revealing inconsistent performance of genotypes across environments. Based on interaction principal component analysis of G × E, the dry pea genotypes, Montech 4152 followed by SW Midas and DS Admiral showed combination of better yield performance and stability. Among the lentil genotypes, CDC Richlea followed by Avondale showed less fluctuation to environmental changes but produced similar yields compared with the high yielding lentil genotypes. Therefore, these dry pea and lentil genotypes can be recommended for cultivation in wide range of environments in the temperate semi-arid climates and similar ecologies.

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1. Introduction

The addition of dry pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) production in the cereal dominated cropping systems provide several long term agronomic benefits and contribute to ensure systems sustainability. Several research results showed that the addition of pulse crops such as dry pea and lentil in such mono-cropping systems contribute to improve soil fertility, reduce disease incidence and minimize weed diversity with overall economic benefits (Chalk et al., 1993; Young et al., 1994; Herridge et al., 1995; Stevenson et al., 1996; Stevenson and Kessel, 1996; Höflich et al., 2000; Liebman and Davis, 2000; Derksen et al., 2002; Krupinsky et al., 2002; Miller et al., 2002; Alvey et al., 2003; Bailey and Lazarovits, 2003; Lupwayi et al., 2006; Yunusa and Rashid, 2007).

Winter wheat (*Triticum aestivium* L.)—fallow or winter wheat–barley (*Hordeum vulgare* L.) are some of the major rotational practices adopted in most part of the Northern Great Palins (NGP). Summer fallow is practiced in the semi-arid area of this region mainly to conserve soil moisture for the next crop season. However,

Abbreviations: AMMI, additive main effect and multiplicative interaction; G × E, genotype by environment interaction; IPC, interaction principal component; SOS, sum of squares.

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Table 1
List of environments (combination of location and year), locations, years and type of crops (dry pea and or lentil) evaluated from 2012 to 2014 across Montana.

Environment	Location	Year	Crop evaluated	Environment	Location	Year	Crop evaluated
BO12	Bozeman	2012	Dry pea	HA13	Havre	2013	Dry pea and lentil
BO13	Bozeman	2013	Dry pea and lentil	HA14	Havre	2014	Dry pea and lentil
BO14	Bozeman	2014	Dry pea and lentil	HU12	Huntley	2012	Dry pea
CO12	Conrad	2012	Dry pea	HU14	Huntley	2014	Dry pea and lentil
CO13	Conrad	2013	Dry pea and lentil	MO12	Moccasin	2012	Dry pea
CO14	Conrad	2014	Dry pea and lentil	MO13	Moccasin	2013	Dry pea and lentil
CR12	Creston	2012	Dry pea	MO14	Moccasin	2014	Dry pea and lentil
CR13	Creston	2013	Dry pea and lentil	RI12	Richland	2012	Dry pea
CR14	Creston	2014	Dry pea and lentil	RI13	Richland	2013	Dry pea and lentil
CV12	Corvallis	2012	Dry pea	RI14	Richland	2014	Dry pea and lentil
CV13	Corvallis	2013	Dry pea and lentil	SI12	Sidney	2012	Dry pea
CV14	Corvallis	2014	Dry pea and lentil	SI14	Sidney	2014	Dry pea and lentil
HA12	Havre	2012	Dry pea				

recognizing the various benefits of growing pulse crops, this traditional cereal based rotation is changed into cereals-spring pulse rotation. For instance in Montana state, USA, the total area planted to spring pulse crops mainly dry pea, lentils and chickpea (*Cicer arietimum* L.) increased from 14,160 ha in 1998 to 242,810 ha in 2014 (USDA-NASS, 2014) mainly replacing summer fallow. This trend is expected to increase since there is a possibility to bring more fallow lands for spring pulse crop production with overall contribution to achieve economic, social and environmental sustainability. Nielsen (2001) showed the agronomic potential and economic benefits of dry pea, lentil and chickpea when grown ahead of winter wheat in the NGP. A similar study in the region reported that dry pea–wheat rotation can reduce net return uncertainties relative to wheat-fallow rotation systems (Miller et al., 2015). However, promotion of pulse crop production in the region require availing information on yield performance of these crops genotypes in wide range of environments.

Some of the States in the NGP, such as Montana, have diverse ecologies in terms of edaphic and climatic factors (Padbury et al., 2002). Genotype by environment interaction (G × E) effect is inevitable in such diverse ecologies due to variation in biotic and abiotic stresses. In addition, this interaction effect is expected since the dry pea and lentil genotypes currently grown in Montana were developed elsewhere. Several studies have shown the significant effect of G × E on yield and quality parameters for various crops (Bassett et al., 1989; Dwivedi et al., 1993; Hoeck et al., 2000; Laghari et al., 2003; Li et al., 2006; Fan et al., 2007; Jandong et al., 2011). Selection of genotypes that produce high yield consistently across different environments is essential.

Yield stability of a genotype is defined as the ability to show a minimum interaction with environmental changes (Eberhart and Russell, 1966). Becker and Leon (1988) pointed out that yield stability of a genotype is directly related to G × E. A successful genotype should produce high yield and should be consistent over a wide range of environmental conditions (Becker and Leon, 1988).

The presence of significant G × E effect caused unpredictability on the performance of genotypes for phenotypic trait such as yield (Becker and Leon, 1988). This complicates genotype recommendation based on traditional analysis using main effects alone (Ebdon and Gauch, 2002; Thomason and Phillips, 2006). The interaction term (G × E) has been considered a critical component to explain yield performance and stability of genotypes, and in identifying the number of mega-environments for genotype evaluation following appropriate statistical tools (Ceccarelli, 1996; Annicchiarico, 1997; Kang, 1997; Yan et al., 2000; Gauch, 2013).

The additive main effect and multiplicative interaction (AMMI) model combines analysis of variance and interaction principal component analysis based on singular value decomposition (Gollob, 1968). These interaction principal components can be used to interpret yield performance and stability of genotypes evaluated in various environments and help to identify mega-environments (Snijders and Eeuwijk, 1991; Gauch, 2006; Baxevanos et al., 2008; Gauch, 2013).

Information on yield performance and stability of dry pea and lentil are rarely available for stakeholders in the NGP involved in these crops production, research, extension, processing and marketing. Therefore, considering the growing importance of these crops and diversity of crop ecologies in the area, evaluating yield performance and stability of dry pea and lentil genotypes in different environments is indispensable. The information generated through this study will help with decision making in the NGP in particular and similar agro-ecologies in general. Therefore, the objective of this study was to determine the yield performance and stability of dry pea and lentil genotypes under temperate semi-arid climates.

2. Materials and methods

2.1. Site description

Experiments were carried out at six Agricultural Research Centers of Montana State University (MSU), Bozeman Post Farm of MSU and on farmer's fields at Richland, Montana, from 2012 to 2014. The combination of location and year was considered as a distinct environment. The experimental locations and environments are shown in Table 1.

Locations were diverse in terms of soil type, elevation, and agronomic management practices (Table 2). In brief, the elevation of the experimental locations ranged from 670 to 1490 meters above sea level (m.a.s.l). The soil texture varied from silty to loam and these differences may cause significant variations in terms of moisture and nutrient holding capacity. Precipitation during these crops growing season (April–August) for all environments ranged from 94 mm at Huntley in 2012 to 424 mm at Sidney in 2013 (Fig. 1). Precipitation in 2012 was generally low for most of the locations compared to 2013 and 2014 (Fig. 1). In 2014, the Richland location experienced an exceptionally cold and wet growing season. In addition, this location received two significant hail events prior to harvest with significant yield loss due to shattering. Therefore, readers should take this damage into account while interpreting the results from this environment (RI14). We intentionally included results of RI14 to provide an insight on yield performance of different genotypes in case of worst weather scenario situations.

2.2. Experiment set up

The dry pea and lentil genotype evaluation experiments were carried out separately in a randomized complete block design with four replications across Montana. The entire dry pea and lentil genotype evaluation experiments consisted of several genotypes