African Journal of Agricultural Research Vol. 7(46), pp. 6197-6203, 5 December, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.644
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Performance of alfalfa varieties with different fall dormancy across different production areas of Henan Province of China

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Accepted 23 July, 2012

Nineteen alfalfa varieties of seven different fall dormancy (FD) classes (2 to 8) over three years in five different eco-agricultural areas with mild climates in Henan Province of China was studied. The results showed that almost all of the varieties exhibited nearly perfect survival rates, while the variety 'Siriver' had a slightly lower survival rate of 98.5%. The variety 'WL414' (FD 6) produced the greatest average dry matter (DM) yield across the regions, while the lowest yield was found in 'Golden Empress' (FD 2). In addition, the total dry matter (DM) yields of the three years were affected by location and variety and there was significant location × variety interaction. The FD classes and total DM yields were significantly correlated, indicating that FD class should be used as one of the main criterion for alfalfa variety improvement or introduction of new varieties into a temperate region, such as Central China. Beside, special attention should also be paid to the selection of varieties suitable to local conditions because other factors have important influence on DM yields, including the characteristics of a varieties and environmental conditions.

Key words: Alfalfa varieties, fall dormancy, dry matter yield, temperate regions.

INTRODUCTION

When selecting alfalfa varieties, researchers and producers in China need to consider several criteria such as yield potential, disease and insect resistance, fall dormancy (FD) and winter hardiness. Fall dormancy refers to the adaptation of alfalfa to particular environments, including shortening photoperiods and declining temperatures in late summer and autumn (Schwab et al., 1996; Fairey et al., 1996; Wang et al., 2008). FD is usually divided into three types: dormant (FD 1 - 3 classes), semi or intermediate dormant (FD 4 - 6 classes), and non-dormant (FD 7 - 9 classes) (Barnes et al., 1979). In autumn, dormant varieties grow very slowly or cease to grow and favor the synthesis and accumulation of soluble sugars, enabling the crops to survive over the hard winter (Castonguay and Nadeau, 1998; Castonguay et al., 1995; Dhont et al., 2002). In contrast, non-dormant varieties continue to grow extensively in the autumn and accumulate small amounts of nonstructural carbohydrates in the roots, leading to low winter survival rates or death in regions with harsh winters (Brummer et al., 2000; Cunningham and Volenec, 1998; Haagenson et al., 2003). The major constraint that prevents widespread cultivations of non-FD alfalfa varieties in cold regions is their poor winter hardiness (Barnes et al., 1979; Stout and Hall, 1989).

In regions where all FD types (dormant, semi-dormant and non-dormant) can be grown, producers are advised to choose non-FD varieties to get higher dry matter (DM) yields (Volenec, 1985). Because of the importance of FD in alfalfa adaptation and productivity, FD class is commonly used as the first index for selecting alfalfa varieties in the United States and Canada (Fairey et al., 1996). In Canada, winter-hardy varieties (FD 1 - 3) are recommended because of very cold environments. In the United States, alfalfa varieties are divided into 10 alfalfa

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Abbreviations: DM, Dry matter; **FD,** fall dormancy.

production zones and different FD classes are recommended for each growing zone. Each variety has its suitable regions for effective and efficient production (Lu and Long, 1992). China is one of the countries where alfalfa grows and it is widely cultivated in the temperate regions, such as in the North and Center. Henan Province is one of China's most suitable regions for growing alfalfa. In all the regions of the Province, mild climates allow all the FD varieties to survive over the winter (Nie and Yan, 2005; Zang et al., 2005), except that the southeast Xinyang region of Henan Province is not suitable for cultivating alfalfa because of high precipitation of more than 1100 mm and acid soils.

Unlike in the United States (Brummer et al., 2000; Haagenson et al., 2003), few studies have been conducted in China to assess the performance of the introduced varieties and to elucidate the relationship between the DM yield potential and the FD class of a variety. Most of the previously published studies (Dhont et al., 2002) in the USA and Canada have emphasized autumn production performance, plant morphology (e.g., plant height) in the autumn, and metabolic chemical differences among different FD varieties in the autumn and winter. However, there has been no attempt to study the relationship between FD class and annual total DM yield. A recent study in a temperate region in China showed that all of the tested varieties were able to survive through the winter, although their FD classes ranged from 2 to 9; and the authors supposed there was no correlation between FD classes and total annual DM yields (Wang et al., 2009). Differences in DM yields were found among different varieties within the same FD class, indicating that FD class should not be considered as the sole and main index for selecting suitable varieties of alfalfa in temperate regions, such as Zhengzhou and other regions with similar climates. Therefore, when selecting suitable alfalfa varieties for extension around Central China, researchers and farmers face the dilemma of considering varieties or autumn dormancy levels.

The specific objectives of this investigation were to: (i) assess the differences in DM yield among 7 FD classes and among varieties of the same FD class of 19 foreign varieties in 5 different ecological regions in Henan Province of China; (ii) further assess whether a quantitative relationship exists between total DM yields and FD classes in these regions, and (iii) verify whether there were FD × region interactions. This information is important for crop physiologists, plant breeders, agronomists and producers, and will expand our understanding of alfalfa variety adaptation in relation to FD in different temperate regions.

MATERIALS AND METHODS

Experimental conditions

The experiments were conducted in five fields, representative of the different ecological regions. The five sites were selected according to different climate conditions with same soil type and similar fertility because FD of alfalfa is affected by climate factors. Anyang is in the northeast region of Henan Province and has low temperature, Sanmenxia with low precipitation and low temperature is in the west mountain of the one, Shangqiu with high precipitation is in the East, Xuchang is with high precipitation and high temperature, while Xinxiang with middle precipitation is in the north. The localizations of the five sites are shown in Figure 1. The annual precipitation, the mean air temperatures and the extreme temperatures of these regions in January and July over the past 10 years and during the study were summarized in Table 1. The total growing degree days (GDD) value of the three growing years was also included in Table 1. There was no exceptional management as extreme weather events took place during the experiment. (in case of extreme cold winter). The soil of each field was a Hapludolls sandy loam (or Eutric Cambisol in the United Nations' classification) and the nutrient contents (0 - 30 cm depth) are summarized in Table 1. In all the locations, the preceding crops were corn (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) before the current study. All the fields were sufficient in potassium (K) but deficient of nitrogen (N) and phosphorus (P) before the current study. During land preparation, 81 kg N ha^{-1} as urea and 96 kg P_2O_5 ha^{-1} as calcium phosphate were applied and incorporated into the soil at 0 to15 cm depth.

The experiments were established under a randomized complete block design with four replications per field. Nineteen alfalfa varieties of FD classes varying from 2 to 8 were included in each field in this study (Table 2). Most varieties were introduced from the United States and Canada; two varieties 'Hunter River' and 'Siriver' were from Australia, while 'Sitel' was the only variety from France. FD class for each variety was provided by the breeding company. Each plot was 13.5 m long and consisted of 10 rows of alfalfa with 0.3 m spacing; the alfalfa was seeded by hand on 8 October, 2003. The seeding rate of all varieties was adjusted by the seed purity and germination percentage to achieve a target population density of 176 plants m^{-2}. The seeds were inoculated with *Rhizobium meliloti* because the land had not been cropped with alfalfa. In all the locations, due to the drought from the autumn through winter, irrigation was provided along with 48 kg N ha^{-1} as urea in early March of each year. There was no additional fertilizer and irrigation during the plants growth period. Weed control was performed by hand or with hoeing as required. The experiments lasted for 3 years (2004 to 2006) according to the general principle of the field experiment (Haagenson et al., 2003; Cunningham and Volenec, 1998).

Estimation of plant survival and dry matter yields

The number of plants in one randomly selected row per plot was counted in early November 2003 and early March 2004. The overwinter survival rate was calculated according to the following formula: survival rate (%) = plant numbers in March / plant numbers in November × 100. The GDD values were calculated according to the following formula: GDD value = $\Sigma(Td - Tb)$ $(Td > Tb)$, where T_b is above temperature of development basis points 5°C, T_d is the mean daily temperature of the whole growth period of each year (from the end of February or in early March to early or mid-October of each year) and Σ is the summation of three years (2004-2006). The dry matter yield was determined for each plot with four cuts per year. Each variety was harvested at the early blooming stage (1/10 bloom). Although the 19 varieties had different FD classes, the difference in early blossom occurrence for each cut averaged only 3 days with extremes of up to 5 days. The alfalfa plants usually start growing at the end of February or in early March of the each year. In all the locations, the first cutting was in early May; the two subsequent cuttings occurred in the middle of June and August; the final cutting for all varieties took place in early or mid-October of

Figure 1. Geographical locations of the 5 experimental sites [Xuchang (a), Sanmenxia (b), Shangqiu (c), Xinxiang (d), Anyang (e)] used in the study.

each year. At each sampling, plants in a quadrant of 2 × 2 m for each plot were cut approximately 5 cm above the ground. After harvest, DM yield was measured by the following methods: (1) about 1.0 kg fresh herbage was randomly taken from each plot and after being accurately weighed, was dried in an oven (GZX-GF101-2-BS) at 65°C until a constant weight was obtained; (2) the above samples were then put in an oven at 105°C until a constant weight was obtained; (3) total DM yield of the three years per hectare was calculated with the formula DM yield (t/ha) = (DM sample weight)/(fresh sample weight) × fresh herbage yield (t/ha).

Statistical analysis

Data were analyzed statistically as a randomized complete block design using analysis of variance procedures (SAS institute, 1999), and the interactions of variety × site and FD class × site were conducted by two-way ANOVA. When *F*-tests were significant ($p \leq 0.05$), the means were compared with the Student-Newman-Keuls multiple mean comparison test. A curvilinear regression analysis between FD class and yield was conducted for each site. However, when curvilinear regression analysis is not significant, linear regression analysis between FD class and yield was conducted for the site.

RESULTS

When measured after the first winter, almost all of the

Table 1. Meteorological data and soil conditions during the study period.

Item	Xuchang	Anyang	Sanmenxia	Shangqiu	Xinxiang
Latitude	34°12′ N	35°95′ N	34°76′ N	34°40′ N	35°14′ N
Longitude	113°47′ E	114°88′ E	111°19′ E	115°87′ E	114°19′ E
Altitude (m)	95	51	700	70	60
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Soil organic matter (mg/kg)	12.7	12.6	12.5	13.2	10.0
Alkaline-N (mg/kg)	117.4	116	107.6	124.3	100.8
Bray-P (mg/kg)	12.8	11.6	10.7	13.5	9.5
Test K (mg/kg)	155.7	173.0	164.2	168.7	140.3
Annual mean air temperature (°C) *	15.4 / 15.2	13.9/14.0	13.2 / 13.3	14.3 / 14.3	14.8/14.5
Extreme temperature in January (°C) *	-8.8 / -10.9	-15.9 / -17.5	-10.4 / -12.5	-11.1 / -15.4	-10.9 /-13.2
Extreme temperature in July (°C) *	38.7 / 40.4	35.5 / 41.2	41.4 / 41.6	37.8 / 38.8	36.4 / 38.6
Annual precipitation (mm) *	850.5 / 766.8	606.3 / 562.8	485.9 / 504.0	861.8 / 805.7	673.6 / 658.3
Total GDD value of the three growing year’3 (≥5°C)	11015.8	10305.1	8636.8	10259.1	10725.3

* The data of temperatures and precipitations were presented as tested year values / long term (10-year) values.

Table 2. Total DM yields (Mg ha^{-1}) of alfalfa during the three years (2004 to 2006) of study in each region.

Varieties	FD class	Xuchang	Anyang	Sanmenxia	Shangqiu	Xinxiang	Mean yield of 5 sites
Algonguin	2	57.81^{bC}	61.63^{abcB}	66.40^{abA}	65.14^{abcA}	57.10^{bcdefC}	61.62^{bcd}
Vernal	2	59.64^{abAB}	58.03^{abcAB}	55.34^{deB}	64.78^{abcA}	52.78^{fgB}	58.12^{ef}
Farmers	2	61.47^{abAB}	59.08^{abcAB}	57.32^{dB}	62.62^{bcA}	48.90^{hC}	57.88^{ef}
Golden Empress	2	51.76^{cB}	55.77^{bcB}	39.90^{hC}	65.80^{abcA}	53.84^{efgB}	53.42^{g}
Grandeur	3	61.20^{abAB}	61.52^{abcAB}	54.80^{deB}	63.52^{bcA}	56.21^{cdefAB}	59.45^{cde}
Alfaking	3	62.02^{abA}	59.50^{abcAB}	48.55^{gC}	64.76^{abcA}	54.17^{defgBC}	57.80^{ef}
WL323HQ	3	60.57^{abAB}	60.89^{abcAB}	64.68^{bA}	65.96^{abcA}	58.18^{bcdeB}	62.06^{bc}
Affinity	4	64.29^{abA}	58.93^{abcAB}	53.20^{eB}	65.37^{abcA}	54.19^{defgB}	59.19^{cde}
Phabulous	4	63.27^{abB}	61.50^{abcBC}	55.87^{deC}	69.04^{abA}	58.28^{bcdeBC}	61.59^{bcd}
WL323	4	62.28^{abB}	61.60^{abcB}	60.00^{cB}	65.46^{abcA}	55.67^{cdefC}	61.00^{bcde}
Apex	4	65.61^{abA}	58.63^{abcB}	54.34^{deB}	64.84^{abcA}	59.81^{bcB}	60.65^{bcde}
Sitel	5	59.21^{abBC}	63.66^{abAB}	54.82^{deCD}	69.36^{abA}	51.04^{ghD}	59.62^{cde}
Archer	5	62.54^{abA}	63.18^{abA}	49.05^{gB}	64.48^{abcA}	61.21^{bA}	60.09^{bcde}
WL-414	6	67.04^{aAB}	63.86^{abB}	68.55^{aA}	65.23^{abcAB}	57.17^{bcdefC}	64.37^{a}
CW608	6	64.38^{abA}	59.03^{abcB}	53.23^{eC}	65.51^{abcA}	54.74^{defgC}	59.38^{cde}
Hunter River	7	62.47^{abA}	59.01^{abcA}	49.52f^{gB}	62.72^{bcA}	58.85^{bcdA}	58.51^{def}
Ameileaf721	7	61.01^{abB}	61.31^{abcB}	55.15^{deC}	63.71^{bcA}	56.65^{cdefC}	59.57^{cde}
Siriver	8	60.46^{abB}	65.50^{aAB}	52.12^{ef}C	71.31^{aA}	65.09^{aAB}	62.90^{ab}
WL525HQ	8	58.94^{abA}	53.20^{cB}	52.34^{efB}	59.56^{cA}	55.40^{cdefgB}	55.89^{f}
Mean yield of 5 sites		61.37^{B}	60.31^{B}	55.01^{C}	65.22^{A}	56.28^{C}	59.64

Within a column (except the last row), means followed by different small letters are significantly different ($P \leq 0.05$); within a row (except the rightmost column), means followed by different capital letters are significantly different ($P \leq 0.05$).

varieties exhibited nearly perfect survival rates, while the variety ‘Siriver’ had a slightly lower survival rate of 98.5%. In the subsequent years, stand persistence for all varieties appeared to be normal, and there were no visible gaps of dead plants in any plots. Even in the Anyang and Sanmenxia regions where the mean temperatures of January and February in 2004 and 2005 were lower than those in other regions, the plant survival rate was unaffected. There was no snow cover as low temperature took place.

Comparisons of dry matter yields among varieties with different FD classes

The varieties differed greatly in the total DM yields of the

Table 3. Total DM yields (Mg ha^{-1}) of the three years (2004 to 2006) of each FD class varieties in the field experiments conducted in each region.

FD Class	Xuchang	Anyang	Sanmenxia	Shangqiu	Xinxiang	Average
2 (n=16)	57.67^{cB}	58.63^{aB}	54.74^{aB}	64.58^{aA}	53.16^{bB}	57.76^{b}
3 (n=12)	61.26^{abcAB}	60.64^{aAB}	56.01^{aB}	64.75^{aA}	56.19^{abB}	59.77^{ab}
4 (n=16)	63.86^{abA}	60.17^{aB}	55.85^{aC}	66.18^{aA}	56.99^{abC}	60.61^{ab}
5 (n=8)	60.87^{abcBC}	63.42^{aAB}	51.94^{aD}	66.92^{aA}	56.13^{abCD}	59.86^{ab}
6 (n=8)	65.71^{aA}	61.44^{aAB}	60.89^{aAB}	65.37^{aA}	55.96^{abB}	61.88^{a}
7 (n=8)	61.74^{abcA}	60.16^{aAB}	52.33^{aC}	63.22^{aA}	57.75^{abB}	59.04^{ab}
8 (n=8)	59.70^{bcAB}	59.35^{aAB}	52.23^{aB}	65.43^{aA}	60.25^{aAB}	59.39^{ab}

Within a column, means followed by different small letters are significantly different ($P \leq 0.05$); within a row, means followed by different capital letters are significantly different ($P \leq 0.05$). FD class × region interaction $P \leq 0.0001$; variety × region interaction $P \leq 0.0001$.

three production years (Table 2). WL-414 (FD 6) produced the greatest total DM yield of 64.37 Mg ha^{-1} and was followed by 'Siriver' (FD 8), while the 'Golden Empress' (FD 2) produced the smallest yield of 53.42 Mg ha^{-1}. The three dormant varieties, 'Alfaking' (FD 3), 'Farmers' (FD 2) and Vernal (FD 2) also produced relatively smaller total DM yields of 57.80, 57.88 and 58.12 Mg ha^{-1}, respectively. (FD 8) (Table 2). From the ANOVA, it is highly likely to find similar performance of a cultivar FD2 to a cultivar FD8.

The total DM yields of all years were affected both by region and variety (Table 2), and there was a significant region × variety interaction ($P < 0.01$). The varieties grown in the Shangqiu location produced the greatest average total DM yield of 65.22 Mg ha^{-1} and was followed by Xuchang (61.37 Mg ha^{-1}), Anyang (60.31 Mg ha^{-1}), and Xinxiang (56.28 Mg ha^{-1}), which were 18.6, 11.6, 9.6 and 2.3% greater, respectively, than that of Sanmenxia (55.01 Mg ha^{-1}) (Table 2). Within a region, the total DM yields of the three years of the alfalfa varieties differed ($P < 0.05$). For example, among the 19 varieties in Sanmenxia (Table 2), WL-414 (FD 6) and Aloguin (FD 2) had the greatest total DM yield (68.55 and 66.4 Mg ha^{-1}, respectively), while 'Golden Empress' produced the lowest yield (39.9 Mg ha^{-1}). From the 19 varieties tested in the Shangqiu region (Table 2), only 5 had low forage yield, highlighting this region as the best for alfalfa production. In the five regions with different climate conditions, there were notable differences in the total DM yields among regions for the same variety. For example, 'Siriver' had the greatest yield of 71.31 Mg ha^{-1} in Shangqiu, 65.5 Mg ha^{-1} in Anyang, and 65.1 Mg ha^{-1} in Xinxiang, but it had lower yields of 52.1 Mg ha^{-1} in Sanmenxia and 60.5 Mg ha^{-1} in Xuchang. 'Golden Empress' produced the lowest total DM yields in three regions: 51.8 Mg ha^{-1} in Xuchang, 55.8 Mg ha^{-1} in Anyang and 39.9Mg ha^{-1} in Sanmenxia. However, it produced a greater total DM yield of 65.8 Mg ha^{-1} in Shangqiu. Likewise, the total DM yields of Sitel also varied: 69.4 Mg ha^{-1} in Shangqiu and lower than most other varieties in Xinxiang. Hunter river, archer, grandeur and WL-323HQ showed the high stability across localities than the rest by performing well in 4 of sites despite the differences in GDD and rainfall, although they did not appear as the highest yielding varieties.

Comparisons of the total dry matter yields of the varieties with different FD classes

The average total DM yields of all sites were affected by FD class (Table 3). FD 6 varieties produced the greatest total DM yields, which were 7.1% greater than that of FD 2 varieties ($P < 0.05$). There were no significant differences in the total DM yields of all years among FD classes 3, 4, 5, 7 and 8. However, total DM yields of all years were affected by FD class and the different regions ($P < 0.01$) (Table 3), and there was also significant correlation between FD class and overall DM yield in all sites ($P < 0.05$) (Figure 2f). For example, in Xinxiang, FD 8 varieties had the greatest total DM yields, significantly greater than varieties of the FD 2 ($P < 0.05$), FD 2-7 varieties did not have significant differences among the total DM yields; curvilinear regression analysis showed that there was a very significant correlation between FD class and total DM yield ($P < 0.01$) (Figure 2a). However, in Xuchang and Anyang, total DM yields of the FD 6 and FD 5 were the greatest, and significantly correlated between FD class and total DM yield (Figure 2b and c) ($P < 0.05$). In Sanmenxia and Shangqiu, the differences among the total DM yields were not significant ($P>0.05$), while linear regression analysis showed the differences were not also significant, although that of FD 6 (Sanmenxia) and those of FD 4, 5 (Shangqiu) were the greatest, respectively (Figure 2d and e).

DISCUSSION

It was proposed that fall dormancy might not always be related to winter hardiness (Li and Wan, 2004). However, few studies have addressed the relationships between FD and annual DM yields, even though variety improvement and its introduction into temperate regions

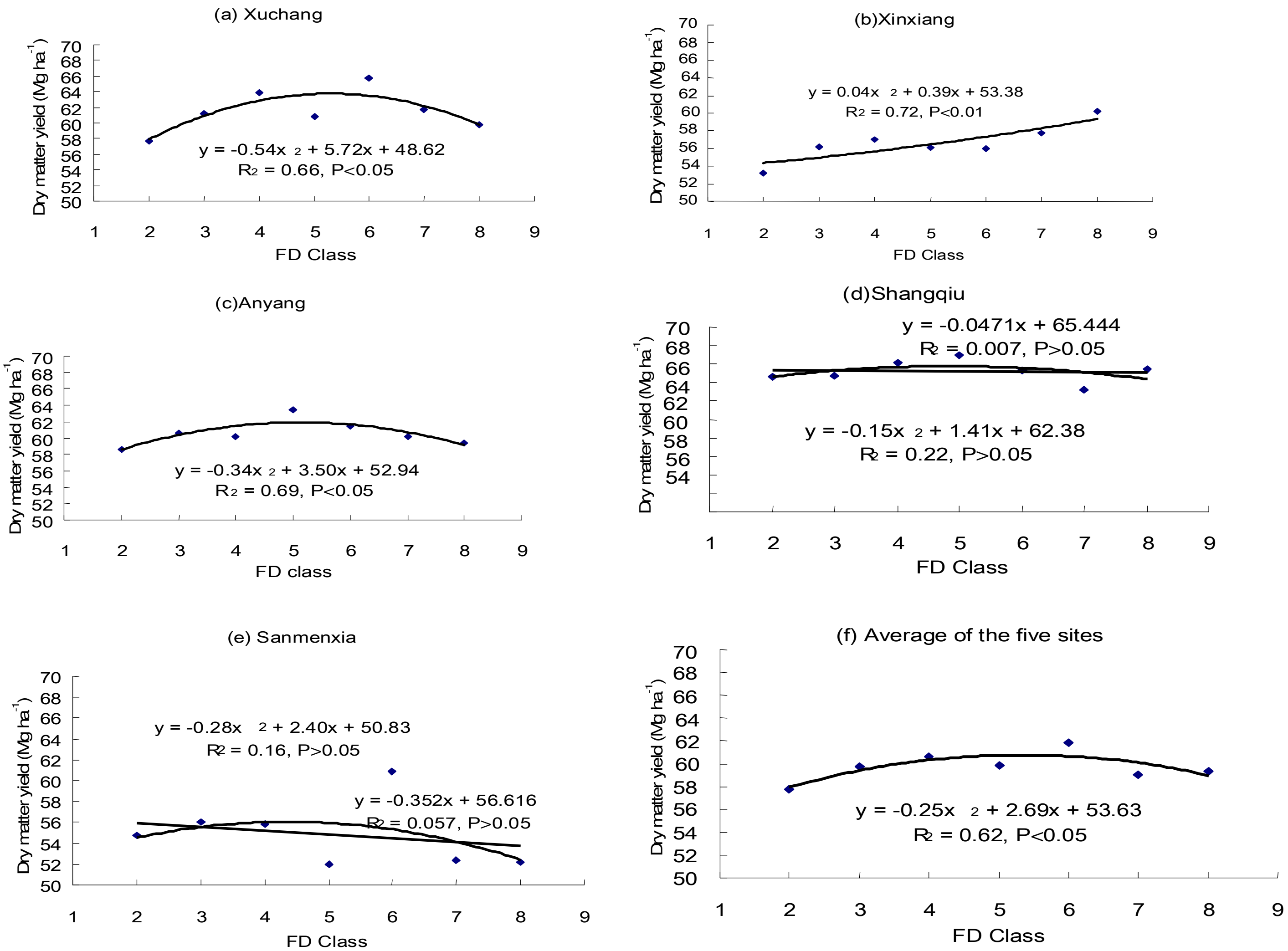

Figure 2. Relationship between FD class and total dry matter yield in each site. The data points are three years means of each FD class in each site.

are based on the annual total forage yields instead of the autumn yields. Recently, several Chinese studies have indicated that there is no well-established relationship in temperate regions of Northern China between FD class and annual herbage yield (An et al., 2003; Li and Zhu, 2005; Wang et al., 2005).

In this study, all alfalfa varieties with seven FD classes in each region overwintered with survival rates > 95% in the first year, and did not appear to be persistent problem for any of the varieties in the subsequent years. The high winter survival rate in this study was associated with the slightly high average winter temperatures in the regions, although the extreme temperatures in January in Anyang reached -15.9℃. In general, in temperate regions with the mild climates in Henan Province of Central China, alfalfa winter survival is important for the initial year of establishment, and there are rarely persistent problems after the first winter (Wang et al., 2005, 2009). The differences in the weather or soil conditions or interaction between class and region were the main reasons for the different total DM yields of varieties among regions. In Shangqiu, the total DM yields of the three production years were significantly greater than those of the other four regions. It is possible that the greatest annual mean precipitations or soil fertility or interaction were in the region. The differences in the total DM yields in different regions were possibly caused by interactions between the climate conditions and fall dormancy of the alfalfa varieties. There were very significant correlation ($P < 0.01$) (Xinxiang) or significant correlations ($P < 0.05$) (Xuchang and Anyang) between FD class and DM yield, suggesting that FD influenced the growth of alfalfa varieties in temperate ecological regions.

The correlation between FD class and DM yield was also significant for five sites, These correlations could be used as one of the primary criteria for selecting suitable FD varieties in temperate ecological regions. On the other hand, there was similar production performance of a cultivar FD 2 to a cultivar FD 8. This implies that not only the FD has an influence, but there are other factors influencing DM yield. This suggests new areas of research for this species. Our data also showed significant differences in DM yields among varieties with the same FD class, implying that varieties with greater DM yield potentials in each FD class are also important in temperate regions with mild climates.

Conclusions

In this study, we found that the differences in the weather or soil conditions may be the major causes of the different annual DM yields among regions. There were significant region × FD or region × variety interactions in the regions with temperate environments and similar soil conditions. There was also a significant correlation between FD class and total annual DM yield in most regions, but the differences in the DM yields were found among different varieties within each FD class. Consequently, FD class should be considered as one of main index for selection of suitable varieties of alfalfa in temperate regions, such as Xuchang and other regions with similar climates. Moreover, special attention should be paid to the selection of varieties suitable to local conditions since there are similar production performance for some varieties of different FD classes, and other factors influences DM yields, including the characteristics of a variety and environmental conditions

ACKNOWLEDGEMENTS

This research was partially supported by the National Science Foundation (Project no. 30771527) and the Earmarked Fund for Modern Agro-industry Technology Research System (CARS-35), People's Republic of China.Thanks to International Center of Papertrans (http://www.papertrans.cn/) for the composition and revision for the manuscript.

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