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Research paper

Indices of forage nutritional yield and water use efficiency amongst spring-sown annual forage crops in north-west China

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ABSTRACT

Livestock production in China is increasing to meet demands for animal products, but is limited by feed resources. To explore additional forage options in north-west China, the biomass production and nutritive value of nine spring-sown annual crops (maize (*Zea mays*), sudan grass (*Sorghum sudanense*), small millet (*Setaria italica*), millet (*Panicum milliaceum*), soybean (*Glycine max*), common vetch (*Vicia sativa*), pea (*Pisum sativum*), oat (*Avena sativa*) and spring wheat (*Triticum aestivum*)) were compared under rainfed conditions over two years. Water use efficiencies for biomass (WUE_{DM}) and nutritional yield indices, CP yield (WUE_{CP}) and relative feed value yield (WUE_{RFV}), were calculated. Maize produced the highest biomass yields of > 10 t DM ha^{-1} and had the highest WUE_{DM}. Biomass production was next highest in the other warm-season grasses such as sudan grass and millet species (6–9 t DM ha^{-1}) and soybean (3–7 t DM ha^{-1}), while spring wheat produced the most early biomass in spring ($P < 0.05$). The legumes had higher crude protein concentration and produced equivalent or higher CP yields and WUE_{CP} to the grasses (1.2–1.7 kg CP ha^{-1} mm^{-1}). Maize and soybean had the highest WUE_{RFV} of 26.4 kg ha^{-1} mm^{-1} and 19.4 kg ha^{-1} mm^{-1}, respectively. These integrated nutritional yield indices enabled comparisons of water productivity and optimal harvest timing across a range of forage types with differing nutritional characteristics and biomass production potential.

1. Introduction

Livestock is a vital source of income for the rural population in developing countries, contributing to livelihoods through production of meat, milk, leather and wool. The demand for livestock products will double globally between 1993 and 2020, with demand for meat and milk products in developing countries growing at annual rates of 2.7 and 3.2%, respectively (Delgado et al., 1999). In China, in particular, demand for livestock products is growing rapidly. On the Loess Plateau of China, the expansion of livestock production is being promoted to enhance rural incomes with governmental programs aiming to double small ruminant numbers in some regions (Brown et al., 2009). This intensification of small farms, combined with a grazing ban that necessitates the pen feeding of animals, has meant that forage sources produced in conjunction with cropping systems will be vital to meet animal forage demand (Komarek et al., 2012).

Currently, livestock production in the Loess Plateau regions relies predominantly on pen feeding collected crop residues (mainly maize and wheat) and lucerne (*Medicago sativa*) (Nolan et al., 2008), but forage shortages and their low quality particularly during winter and early spring limit livestock production (Komarek et al., 2012). These feed gaps can result in livestock weight losses of 20–30% in winter and early spring (Kemp and Michalk 2011) and hence greatly restrict farmers' income and the subsequent economic development of a regional livestock industry (Hou et al., 2008). Thus, it is necessary to resolve the feed deficit in winter and early spring by supplementing forage supplies with other feed sources. In order for farmers on the Loess Plateau to meet the competing demands of increasing animal intensity while maintaining sustainable grain production alternative forage sources need to be identified.

Two significant opportunities exist to integrate annual forage crops within the wheat–maize cropping system typically used in the region. The first, and focus of this study, is to examine the potential of existing spring-sown crops grown as forages (e.g. maize, soybean, spring wheat) or partial replacement of these with alternative spring-sown forage crops (e.g. millet, oats, vetch) after which a winter wheat crop is sown in September and harvested between end of June and early July the following year. The second is to sow an autumn forage crop following wheat harvest instead of a short summer fallow prior to winter.

When selecting the most suitable forage species, firstly, it is

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Table 1
Monthly rainfall and total growing season (GS) rainfall (mm month^{-1}) during experimental years of 2009 and 2010 and long-term mean (LTM, 1961–2008) rainfall (mm) at Xifeng Research Station, Gansu, China.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	GS
2009	2	14	18	10	49	34	115	126	37	14	14	20	385
2010	0	10	97	116	39	47	106	205	37	100	3	17	650
LTM	4	6	20	38	53	65	109	102	90	42	17	4	498

important to understand their biomass production but also their nutritional value for livestock. In particular, key forage quality parameters such as crude protein concentration (CP), fibre concentrations and metabolizable energy are frequently used to assess the relative nutritive value of forages for livestock (Stockdale 1999; Coleman and Moore, 2003). Biomass production and these forage quality attributes will change throughout the growing season with stage of growth and as plants increase the proportion of stem compared to leaf, with forage quality typically declining as biomass yield approaches maximum (Beever et al., 2000). Hence there is a trade-off between maximizing biomass yield and forage quality attributes that requires both factors to be considered in order to optimize timing of harvesting or grazing to maximize nutritional yield (de Ruiter et al., 2002). Calculating indices of nutritional yield, which integrate both biomass production and nutritional value could provide a useful methods to compare a broad range of forages with differing characteristics and identify optimal forage harvest management for these species. Secondly, in water-limited environments, forages which have highest water productivity or efficiency of converting available water resources into product (Water use efficiency, WUE) is an important criterion (Neal et al., 2011; Wallace 2000). This is particularly important to consider when comparing species which differ in their length of growing season or degree that they extract soil water (Bell et al., 2012; Garcia et al., 2008). Many studies have examined water use efficiencies for dry matter (WUE_{DM}) and grain yield (WUE_{GY}) and the effects of agronomic management of grain crops in the Loess Plateau (Huang et al., 2003; Deng et al., 2006; Jin et al., 2007; Xu et al., 2008; Liu et al., 2010). However, to our knowledge no other studies have examined WUE for these crops when they are managed as a forage crop, where they are harvested before maturity. Similarly, we are unaware of any studies which have experimentally examined WUE of dryland forage crops using indices which integrate both biomass production and forage quality (as discussed above). We believe this approach could be applied more widely in the evaluation of forage crops in water-limited environments.

In this paper we hypothesised that using integrated biomass-nutritional value indices and water-use-efficiencies for these indices would be valuable to identifying the most prospective annual crops for use as forages and their optimal harvest timing for livestock production in the Loess Plateau of north-west China. Therefore, the study compared nine locally grown annual crops when grown for forage production in spring over two growing seasons on the Loess plateau region of north-west China. Measures of biomass production, crude protein and fibre concentrations throughout the growing season were used to calculate crude protein (CP_{yield}) and relative feed value yields (RFV_{yield}) and crop water use was measured to calculate water use efficiencies for biomass (WUE_{DM}), CP yield (WUE_{CP}) and RFV yield (WUE_{RFV}) per mm of water.

2. Material and methods

2.1. Site description and experimental conditions

This study was conducted at the Lanzhou University Loess Plateau Research Station (35°40′ N, 107°51′ E, elev. 1298 m), located in Xifeng city, Gansu province, in northwest China during 2009 and 2010. The region is in the rainfed agricultural production zone of the western Loess Plateau. Average annual long-term precipitation is 561 mm, varying from 320 to 820 mm in 50 years. The average annual temperature is 8.3 °C. The average annual solar radiation is 5489 MJ m^{-2}. On average the growing season extends from March to October and lasts around 255 days. The soil is a very deep loess silt-loam classified as Heilu (Zhu et al., 1983) or Entisol in the US classification., The soil has a uniform profile with the surface 0.2 m having a pH of 8.2, organic carbon content 6.8 g kg^{-1}, total N 0.84 g kg^{-1}, and bulk density 1.30 g cm^{-3}. The plant-available water-holding capacity is 419 mm to a depth of 3 m.

Growing season rainfall between April and October was 385 mm in 2009 which is lower than the long-term average of 490 mm. Spring and early summer and autumn 2009 were all significantly below average rainfall. On the other hand, the 2010 growing season received above average rainfall (650 mm) and had above average rainfall in spring and summer (Table 1).

2.2. Experimental design and management

The nine annual crops suitable for spring sowing in the region were assessed for their forage potential. These included maize (*Zea mays*), sudan grass (*Sorghum sudanense*), millet (*Panicum milliaceum)*, and small millet (*Setaria italica*), soybean (*Glycine max*), common vetch (*Vicia sativa*), pea (*Pisum sativum*), oat (*Avena sativa*), and spring wheat (*Triticum aestivum*). The crops were sown by hand on the same date in early spring (18 April 2009 and 17 April 2010) in 5 × 6 m plots in a randomized complete block design with four replications. Crop cultivars, sowing rate and established plant density are shown in Table 2. Maize and sudan grass were sown with 40 cm spacing while all other

Table 2
Details of crop cultivar and seeding rate used in experiments and established plant density in 2009. In 2010, seeding rates were the same with good establishment was observed but plant density was not recorded.

Forage species	Cultivar	Seed rate (kg ha^{-1})	Plant density (plants m^{-2}) ± standard error
Maize	Cheng3395(2009), Denghai (2010)	44	29 ± 1
Sudan grass	Caishi	23	23 ± 6
Small millet	Long Gu 11	23	86 ± 8
Millet	Long Mei 9	23	86 ± 4
Soybean	Hei Feng 48	75	56 ± 1
Common vetch	Long Jian 3	75	99 ± 1
Pea	9929	75	58 ± 3
Oat	Qingyin 2	30	124 ± 10
Spring wheat	Long Jian	150	191 ± 13