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Implications of White Clover Introduction in East Himalayan Grasslands



White clover (*Trifolium repens*) introduced in the 1970s has become the most important fodder legume in Bhutan and there is some concern about its possible negative influence on native plant communities. Detailed plant

and soil observations were made across 27 sites (2600–4000 m) to evaluate the effects of white clover on plant community, P dynamics, and fodder quality.

Arundinella hookeri was the dominant species up to 3500 m. Other important species with wide distribution were *Eragrostis nigra*, *Brachypodium sylvaticum*, *Potentilla* spp. and *Schizachyrium delavayi*. An increasing presence of white clover reduced the proportion of biomass from other species, the frequency of *A. hookeri* and *Potentilla* spp., and the proportion of bare ground. Biomass harvested from spots with high white clover presence had 70% higher N and 17% higher P content when compared to biomass from spots with no white clover. Soil available P (Bray) was 2.68 mg/kg for patches without white clover and 6.21 mg/kg for patches with high white clover presence. There is no indication that white clover could become a weed in permanent grassland environments of Bhutan.

Keywords: *Arundinella hookeri*; diversity; fodder quality; soil parameters; plant–soil P dynamics; Bhutan.

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Introduction

Bhutan has extensive grasslands, which cover approximately 10% of its total land area (MOA 1997). The bulk of the grassland area is found at elevations above 2500 m, with temperate and alpine climates. Fodder from permanent grasslands was estimated to contribute over 30% of the fodder requirement of Bhutan's large livestock population consisting of about 313,300 cattle, 19,100 yak and 8400 horses (NSB 2005). Furthermore, grasslands are important habitats for Bhutan's outstanding range in biodiversity (MOA 2002). Dry matter yields from the Bhutanese grasslands were estimated to range from 0.7 to 3.0 t/ha for temperate grasslands (elevations < 3000 m) and 0.3 to 3.5 t/ha for subalpine grasslands (elevation > 3000 m; Roder et al 2001). Yields are mostly limited by poor phosphorus (P) and nitrogen (N) availability, as rainfall is adequate during the summer months (NSB 2005).

Little information is available on the vegetation composition of these grasslands. Noltie (2000) described grass communities for 3 vegetation types in the temperate areas: 1) Chir pine (*Pinus wallichiana*) forest (900–1800 m), 2) cool temperate grassland (2300–3000 m), and 3) subalpine pasture (3600–4000 m). Legumes are present in all 3 types but their contribution to dry matter production and fodder quality is usually insignificant (Roder et al 2001). Legume species with a wide distribution in natural grassland communities include *Astragalus leucocephalus*, *Astragalus bhotanensis*, other *Astragalus* spp., *Desmodium* spp., *Gueldenstaedtia himalaica*, *Hedysarum* spp., *Lespedeza* spp., *Parochetus communis*, and *Vicia tibetica* (Polunin and Stainton 1984; Roder et al 2001).

Based on distribution and nutritional importance, white clover is the most important pasture legume in humid temperate grasslands throughout the world (Gibson and Cope 1985; Sanderson et al 2002). It spread through Europe and Western Asia before recorded history (Gibson and Cope 1985) but was not found in Bhutan in the 1970s (Roder et al 2001). The first recorded introductions of white clover to Bhutan were in 1970 (Roder et al 2001). Many early attempts at white clover establishment failed due to the absence of effective rhizobia and/or poor P availability. Inoculation of seed with appropriate rhizobia strains was a standard practice used for white clover establishment. In various studies white clover introduction and application of P increased dry matter production of native grasslands from < 2 t/ha to > 10 t/ha (Gyamthso 1984; Roder et al 2001). Over the last 3 decades white clover has been the most widely used exotic fodder species in Bhutan and has proven to be the most suitable legume for grassland improvement over a wide range of conditions between 2000 and 4000 m (Gyamthso 1996). In addition, the species and the associated rhizobia have spread through seed, manure, and soil or plant particles carried by grazing animals.

White clover is generally well appreciated for its fodder quality and high yield, but it can also be a problem because of its bloat-causing characteristics and its persistence in crop fields (Roder et al 2001). The rapid spread of the newly introduced species has therefore caused concern among extension specialists, foresters, and policy-makers. While some have called for caution in future extension programs (Duba et al 1995), others have denounced it as a serious weed, or even condemned it as a menace to existing biodiversity (Roder 1996). In 2 surveys carried out in Bhutan, respondents confirmed that they see clover as a weed in cultivated fields, but that they like clover nevertheless because of its high milk production potential (Roder et al 2001). In a survey covering 2 villages in Bumthang district, white clover was ranked among the 5 most important

weed species (Choden 1997). In a second survey covering 603 households from 4 districts, 70% of the respondents said they were using white clover, 45% mentioned it as causing bloat, and 29% considered it to be a weed in cultivated fields (Roder et al 2001).

Although “being a weed in cultivated fields” may not lead to concerns related to biodiversity, there is a need to assess the impact of white clover on traditional grassland communities. Negative effects of white clover on species diversity in natural grassland communities have been reported from a wide range of environments (Warren 2000; Petryna et al 2002; Sanderson et al 2002). Furthermore, there is a tendency for species diversity to diminish with increasing levels of biomass production (Naeem 2002).

In order to address concerns arising from the spread of white clover in native grassland environments, a study was carried out in 2001 to:

- Document the influence of white clover on plant communities of permanent grassland;
- Describe conditions favoring white clover expansion and soil P and plant interactions.

The study was expected to provide quantitative information to be used in future discussions on the positive and negative effects of white clover on dry matter production and quality, soil fertility, species composition, and biodiversity. Experience in Bhutan may be relevant for other Himalayan or temperate regions at similar latitudes where white clover is present or being introduced.

Materials and methods

All sample sites were located in Bumthang district, central Bhutan, at latitudes ranging from 27°–28°N. The average annual rainfall recorded across the sites varied from 776 to 1333 mm, depending on elevation and topography (RNR-RC Jakar 1998). A total of 27 sites were selected using the following criteria: 1) grassland used for grazing large ruminants (cattle or yak); 2) sites representing altitudinal ranges from 2600 to 4000 m; and 3) sites where patches with high clover dominance can be found next to patches with little or no clover. The grazing pressure was not uniform across the sample sites. No reliable information is available on stocking rates, which are estimated to range from 0.1 to 0.5 live-stock units/ha. As the time of observation coincided with the end of the growing season, grazing pressure was moderate in most places. Most sites are exposed to heavy grazing pressure during the dry winter period.

At each site, within a radius of 5 m, 6 sampling quadrats (25 x 25 cm) were selected arbitrarily for each treatment of T1) patches with high clover presence,

T2) patches with medium clover presence, and T3) patches with little or no clover. For high altitudes it was not possible to find patches with high clover presence, and for those sites observations were limited to T3. The following records on vegetation were collected from each quadrat: 1) visual estimate of the contribution to the biomass by white clover, grass/sedge species, and by broadleaf species and estimates of bare ground; 2) weight of above-ground biomass, clipped and oven dried at 70°C; and 3) frequency of individual species based on presence in the quadrat.

A “proportional frequency” was calculated for the 4 most important grass species as follows:

$$\text{Proportional frequency (\%)} = \frac{\text{Frequency of individual species}}{\text{sum of frequencies for all grass species}} \times 100$$

From each quadrat a soil sample to a depth of 15 cm was collected using an Oakfield core sampler (17 mm diameter). Soil samples and plant biomass from the 6 quadrats of the same treatment were bulked for individual sample sites. Oven-dried plant biomass was milled and analyzed for ADF (acid detergent fiber), N, P, K, Ca, and Mg (SPAL 1998). Air-dried soil samples were analyzed for C, N, available P (Bray), available K, exchangeable Ca, exchangeable Mg, CEC (Cation Exchange Capacity), and pH (SPAL 1998). All analytical work except ADF was carried out by the National Soil Service Centre, Simtokha. Standard statistical methods including analysis of variance (using individual sample sites as replicates) and regression were used to evaluate the data generated.

Results

Grassland vegetation and the influence of white clover

The average standing biomass observed in the vegetation study was only 350 kg/ha. Yields were low because most of the sample plots were exposed to unlimited grazing and because of the inherent low dry matter production of Bhutanese grasslands. The standing biomass measured was not influenced by altitude or clover presence. At most sites below 3500 m, grass species provided the bulk of the biomass for the non-clover plots (Figure 1). With increasing altitude, the grass species are gradually replaced by broadleaf species. *Arundinella hookeri* (Munro ex Keng) dominates the vegetation across a wide range of conditions over the elevation range from 2600 to 3500 m (Figure 2). Other species with high frequencies are *Eragrostis nigra* (Nees ex Steudel), *Brachypodium sylvaticum* [(Hudson) P. Beauvois], and *Potentilla* spp.; *Schizachyrium delavayi* [(Hackel) Bor], considered the most important constituent of cool temperate grasslands by Noltie (2000), was found only at few sites and dominated only at one site. *A. hookeri* was

FIGURE 1 Contribution of grasses (including sedges) and broadleaf species to standing biomass, as influenced by elevation (only data from plots without clover were used).

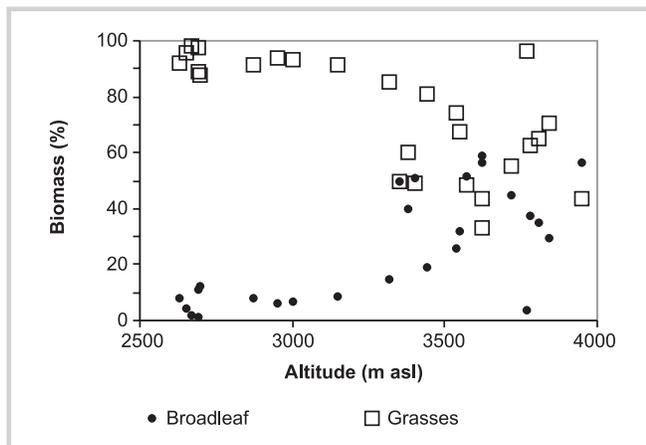
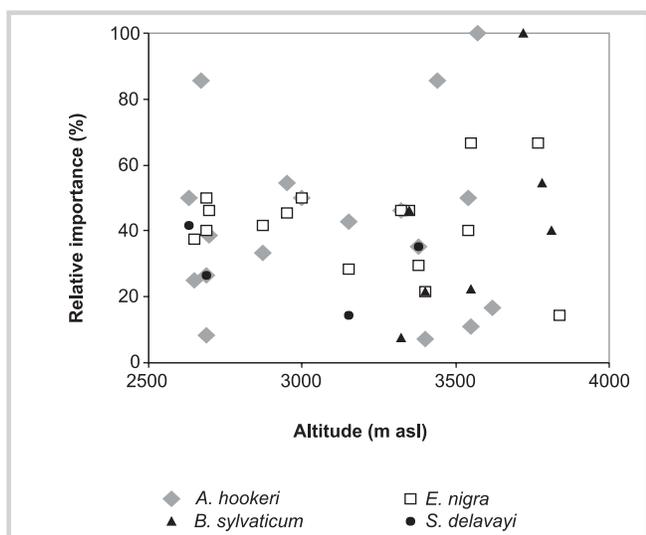


FIGURE 2 Relative importance (in % of all grass frequencies) of the most common grass species at the range of 2600–4000 m (only data from non-clover plots were used).



found at 18 of 27 sites, *E. nigra* at 16, *B. sylvaticum* at 7, and *S. delavayi* at 4. Legumes are rare and consequently the N level of the soil is low.

White clover, although distributed over great distances, has not colonized large proportions of the grassland area. In many places it was therefore difficult to find spots with high proportions of white clover cover. For plots with high white clover cover the contribution of white clover to the total biomass was usually high and thus reduced the relative contribution of grass and broadleaf species to the total biomass (Table 1). The proportion of bare ground tends to be higher without white clover, indicating that white clover does not displace plants but fills gaps. Compared to plots with no white clover, plots with medium or high white clover also had a lower frequency of *A. hookeri* and *Potentilla* spp., but white clover did not affect species diversity measured as the number of broadleaf species and grass species present.

Soil conditions favoring white clover

A strong relationship between available soil P and clover presence was observed, but high variation in P availability reduces the statistical significance. There was, however, no evident relationship (no correlation) between available soil P and the presence of local legume species. The available soil P levels in the high clover plots were 132% higher than the soil P level in non-clover plots ($PR > F = 0.09$, Table 1). The soil P levels had a strong influence on the P content of the plant biomass (Figure 3), but high variation resulted in a R^2 of only 0.32.

No relationship was found between other soil parameters and clover presence. It appears that the typical *A. hookeri* grassland environment is not favorable for white clover, because soils are poor in available P and have poor water-holding capacities. White clover thrives much better in fertile, cultivated fields, and it is in this environment where farmers see it as a weed (Choden 1997; Roder et al 2001). The native plant species are adapted to the low P availability, as they have evolved under these conditions. The P content observed was 0.17% for *A. hookeri* and 0.13% for *Yushania microphylla*, a spreading bamboo species dominating large areas of grassland at elevations of 2300 to 3700 m.

White clover effect on fodder quality

The presence of clover increased the fodder quality substantially, as indicated by the higher N and P content and the lower ADF content (Table 1). Plots containing white clover are generally grazed more heavily than other plots (based on plant height observed, not measured) indicating a higher palatability. There was a close relationship between clover presence and plant N (Figure 4, $R^2 = 0.54$, $PR > F < 0.01$).

The presence of clover increased protein (N content) by 70% and P content by 17%, and decreased ADF content by 9% (Table 1). The increased nutritional quality indicated by these changes substantially increases the milk production potential of grazed vegetation.

Discussion

Soils in the temperate part of Bhutan are generally deficient in P. Furthermore, the diet of grazing animals in temperate areas of Bhutan is generally deficient in P, reducing productivity and fertility rates of cattle (Tshering et al 2003). The extension program under the Ministry of Agriculture has promoted the use of fertilizers through recommendations and subsidies for the last 4 decades. The combined effects of white clover introduction and P application are dramatic for most grasslands of temperate Bhutan, resulting in substantial increase in dry matter production, dry matter quality and livestock production. Because of this effect and the species

TABLE 1 Selected vegetation, plant, and soil parameters for plots with varying levels of white clover presence. PR>F: Probability of larger F; LSD: Least significant difference.

Parameter	High clover	Medium clover	No clover	PR>F	LSD (5%)
Vegetation					
Broadleaf biomass (%) ¹⁾	19.7	30.1	72.8	0.008	8.2
Clover biomass (%)	63.5	15.2	0.1	<0.001	6.5
Grass biomass (%)	27.2	69.9	80.3	<0.001	8.2
Biomass yield (g/m ²)	36.1	34.0	35.3	0.78	–
Bare ground (%)	3.3	8.5	15.3	0.08	–
Number of all species	7.0	7.7	8.2	0.20	–
Broadleaf species (number)	3.3	3.4	3.7	0.12	–
Grass species (number)	3.5	4.0	4.0	0.12	–
Legume species (number)	0.17	0.28	0.44	0.11	–
<i>Arundinella hookeri</i> frequency	31.5	50.0	69.4	<0.001	3
<i>Schizachyrium delavayi</i> frequency	13.0	11.1	15.7	0.48	–
<i>Eragrostis nigra</i> frequency	63.9	64.8	68.5	0.61	–
<i>Agrostis</i> spp. frequency	5.6	9.3	13.9	0.16	–
<i>Potentilla</i> spp. frequency	68.5	75.9	84.3	0.01	10.1
Plant					
N (%)	2.33	1.67	1.37	<0.001	0.17
P (%)	0.256	0.236	0.218	0.015	0.025
K (%)	2.12	1.64	1.37	<0.001	0.16
Ca (%)	0.78	0.64	0.51	<0.001	0.067
Mg (%)	0.16	0.15	0.14	0.26	–
Acid detergent fiber (%)	36.3	38.7	39.7	0.005	1.93
Soil					
Available P (Bray, mg/kg)	6.21	4.46	2.68	0.09	–
Organic C (%)	3.58	3.57	3.35	0.50	–
Total N (%)	0.27	0.27	0.26	0.80	–
Available K (mg/kg)	0.66	0.71	0.80	0.05	0.14
Exchangeable Ca (me/100g)	4.56	3.97	3.33	0.07	–
Exchangeable Mg (me/100g)	0.77	0.67	0.65	0.24	–
CEC (me/100g)	18.3	18.1	18.0	0.95	–
pH	5.86	5.79	5.72	0.06	–

¹⁾Clover not included

FIGURE 3 Relationship between available soil P (Bray) and plant P content; $R^2 = 0.32$, $P < 0.001$.

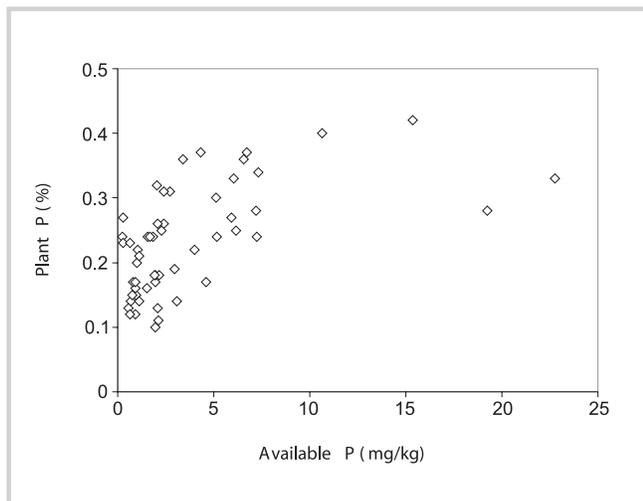
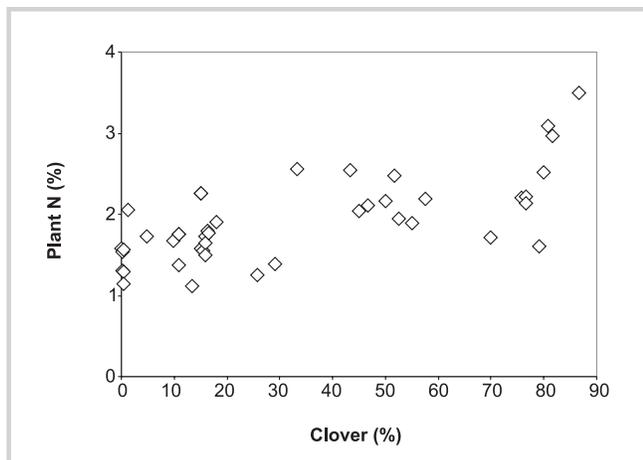


FIGURE 4 Relationship between cover by white clover (%) and plant N (%); $R^2 = 0.54$, $P < 0.01$.



capacity to invade native plant communities, ecological concerns are likely to arise.

White clover effect on species diversity in native grassland

Within a relatively short time after its introduction, white clover spread over great distances. The species will spread further, especially through seed carried by livestock. Our findings indicate, however, that the impact on species diversity on permanent grassland is limited. White clover cannot invade undisturbed grassland environments, and in most situations it was difficult to find patches with high white clover presence. At elevations above 3600 m individual white clover plants were present, but it was not possible to find sites for treatments 1 and 2. The following observations will be important in an assessment of the potential impact of white clover on the biodiversity of grassland environments:

- It is well established that diverse communities are more resistant to invasion by exotic species (Kennedy et al 2002).
- In the absence of grazing or cutting, the prostrate growing white clover can not compete with tall growing species.
- Below the tree line (about 4000 m) most grassland communities are man-made, owing to the influence of logging, fire and grazing. Current species compositions evolved as a response to the influence of humans and animals.
- The most common native species are well adapted to low soil P content. For example, *A. hookeri* has a P content of plant biomass of only 0.17%, while the average P content was 0.22% for the non-clover samples and 0.26% for the high-clover samples.

The situation will change if soil P levels are increased by the application of fertilizer. In this situation, white clover will spread and indigenous species which evolved under low P and N fertility levels will lose their comparative advantage. Higher white clover presence will further increase the fertility status of the soil and result in higher grazing intensities. The combined effect of increased soil fertility, white clover competition, and changes in grazing intensity will bring about a gradual shift in vegetation composition. While this shift may lead to greater biomass production and better fodder quality, it will at the same time result in reduced resilience of the vegetation to external impacts and to a reduction of overall biodiversity.

Development issues

Farmers, herders, and others interested in increased livestock production need to improve fodder production and quality. Introduction of a suitable legume, combined with P application, is the best option presently available. In addition to increased livestock production, higher fertility levels of grasslands and fields temporarily used for fodder production will also increase the overall fertility of a particular farming unit. Thus, improvements in fodder production will directly benefit horticulture and field crop components of the production system.

Present rules and regulations governing grassland use, however, do not allow optimal use of these resources (Roder 2002). Due to uncertain ownership and long-term tenure, farmers and herders are usually not motivated to make investments in grassland improvement. There is a need to create a suitable legal/social environment to optimize benefits from growing improved fodder. Besides increased livestock production, this would also include benefits from synergistic effects of growing fodder in field crop, horticulture, and forest systems.

In the interest of overall agricultural development it may be advisable to provide incentives for optimum P

management through a subsidy system which favors import of P fertilizers and optimizes biological N fixation but discourages import of N fertilizers and animal feed. Mechanisms could include: subsidies for phosphate fertilizer, taxes for nitrogen fertilizer, strict rules about stray animals, etc. At the same time, there is a need to reassess the place of white clover in future fodder development activities and to identify alternative techniques and species that:

- Have lower P requirements and are more efficient in taking up P;
- Can accumulate good quality fodder over the entire growing season, which will then be available for winter feed; and
- Are less susceptible to water stress.

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When assessing the potential impact of white clover on Bhutanese or Himalayan grassland environments, one has to consider the combined effects of the introduced species and management interventions. Management changes which can bring a tenfold production increase will certainly have a strong influence on the entire production system.

Although white clover spreading further across Bhutanese or Himalayan grasslands may not be much of a concern, the combined effects of management changes are likely to influence the vegetation composition and biodiversity. In order for the livestock production industry to benefit from the opportunities in yield and fodder quality increase arising from white clover introduction, it will be necessary to reconcile the needs of biodiversity conservation and livestock development and to reassure ecologists.

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