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*Full Length Article*

# An Experimental Study of Variety Screening, Sequential Cropping, Compaction and Mixed Cropping Techniques for the Cultivation of Annual Forage Crops in Agro-pastoral Area of Tibet, China

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## Abstract

Field experiments were conducted in Jangdam, in the Tibetan plateau of China, to investigate the forage production potential of oats (*Avena sativa* L.),forage-type triticale (×*Triticosecale* Wittmack) and common vetch (*Vicia sativa* L.).The forage productivity of oats and forage-type triticale were evaluated in comparison with local naked barley (*Hordeum vulgare* L.) in single and sequential cropping systems, with and without a compaction roller. The effect of mixed cropping oats with common vetch on the yield and quality of forages was also examined for different seeding ratios. Hay yield, seed germination, and crude protein content were determined for each of the cropping systems. The results revealed that oats and forage-type triticale produced a significantly higher hay yield than local naked barley in both single and sequential cropping systems. Sequential cropping significantly enhanced the total forage yield to 12.4 Mg ha$^{-1}$ for oats, compared to single cropping (8.7 Mg ha$^{-1}$). The seed germination percentage was significantly increased in compacted soil after sowing, which also leads to higher hay yield. Mixed sowing of oats with common vetch brought a protein-rich harvest with a higher or equivalent yield than single-sown oats. The crude protein concentration of the whole forage decreased with the decrease in the seeding ratio of common vetch; the seeding ratio of 70% oat and 100% common vetch achieved a higher forage yield and protein content than the other mixtures studied. © 2014 Friends Science Publishers

**Keywords:** Annual forage; Compaction roller; Mixed cropping; Sequential cropping; Tibet

## Introduction

Since ancient times, pastoral agriculture in Tibet, China has been dominated by various types of short-grass vegetation that have expanded through wide areas of the Plateau. The predominance of grassland vegetation in Tibet (two thirds of the total land area is classified as grasslands and rangelands) is mainly due to the extraordinarily elevated altitude, which averages more than 4,000 m above sea level, and the prolonged cold, dry climate. This vegetation is quite sensitive to external stresses such as overgrazing, climatic changes, etc (Thompson *et al.*, 1993; Thompson *et al.*, 2000; Joosten *et al.*, 2008; Wen *et al.*, 2010).

During the recent economic development, the number of domestic animals has increased rapidly and is approaching nearly 25 million, which includes 4 million yaks and 11 million sheep; these livestock now require approximately 40 million tons of hay over the winter (Yu *et al.*, 2010). However, the actual hay production (mainly derived from wild grasses containing oat plants) in all of Tibet provides only half of the animal demand, so the animals face semi-starvation. This fact seriously threatens the traditional Tibetan society with overall grassland degradation. Reports have shown the apparent expansion of desertification and soil erosion in various areas of Tibet (Harris, 2010; Dong *et al.*, 2011). In this context, the regulation of grazing intensity and the introduction of improved forage cultivation are both urgent needs for the conservation and recovery of Tibetan grasslands (Ding *et al.*, 2007; Wang *et al.*, 2008). However, the natural facets of the region, such as the severely cold climate in winter and the barren soil, restrict the improvement of grassland exploitation. On the contrary, the spring and summer seasons supply rather moderate temperatures accompanied by significant rainfall in the so-called 'river regions' in the south and southeast of Tibet known as the Lhasa and Shigatse areas. In fact, agronomy has been long practiced in parallel with traditional stock breeding, and the total arable land area in Tibet is greater than 0.36 million ha (Dai *et al.*, 2011), supplying a considerable amount of food for the ca.2.8 million inhabitants of the region. Therefore, the use of farmlands to cultivate high-yielding forage crops (spring annuals in particular) that are suitable for the local environment has attracted considerable attention. The cultivation of improved forage crops will provide additional fodder for the animals, which will reduce grazing pressure

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on grasslands, allow farmers to expand their herd size, and satisfy the urgent need for forage products in both local and extra-local places in Tibet. Meanwhile, the improved forage cultivars and cultivation skills will provide more economic benefits than that of local naked barley, which has long been utilized as a traditional food crop in Tibet. This will result in more efficient land utilization for sustaining fodder and food grain production in the Tibet region.

The selection of a forage crop is based on its safety, palatability, energy and nutritional values, as well as its suitability for the plateau climate in Shigatse, Tibet. The oat (*Avena sativa* L.) is an important minor crop in western and semi-arid regions of China (Liu *et al.*, 2011). Because of its tolerance of infertile soils and arid environmental conditions, the oat can adapt to many types of barren places (Suttie and Reynolds, 2004; Burrows, 2005; Martineza *et al.*, 2010). Moreover, the oat has high nutritional value and can be used as a forage crop (Marinissen *et al.*, 2004a, b; Dong *et al.*, 2006; Marinissen *et al.*, 2006; Marcenac *et al.*, 2009). Triticale (×*Triticosecale Wittmack*) is a cross hybrid of wheat and rye that carries the A and B genome of durum wheat and the R genome of rye (Varughese *et al.*, 1997; Sullivan *et al.*, 2007). Triticale displays the high yield and good grain quality of wheat with the better abiotic stress tolerance of rye, including disease resistance (Varughese *et al*., 1997; Anil *et al.*, 1998).Common vetch (*Vicia sativa* L.), an annual legume with high protein levels that climbs as it grows, is usually grown in mixtures with small grain cereals for hay or forage production. These mixtures can improve growth conditions and forage harvesting (Anil *et al.*, 1998).

The objectives of the present work were to investigate high yield productivity with different cropping systems of annual forage plants in agro-pastoral areas of Tibet. We sought to evaluate the effect of a sequential cropping system on the forage productivity of oats and forage-type triticale, compared with the productivity of local traditional naked barley, together with or without additional soil compaction using a land roller. Finally, this study aimed to evaluate the effect of sowing a mixture of common vetch with oats at different seeding ratios on the yield and quality of forages.

## Materials and Methods

### Experimental Site and Plant Materials

The research site was located in jangdam village (approximately 200 km west of Lhasa) in Shigatse, Tibet (approximately 29° 08' N, 89° 01' E). The research fields were along the Yarlung Zangbo River and were covered with sandy soil. The average annual temperature, effective accumulated temperature and sunshine duration in this region are 6.3 °C, 2,800°C and 2,937 h, respectively. The mean annual precipitation is 420mm, and 80% of the precipitation is in the summer season (from June to August). In the research year, the maximum temperature was much higher and the precipitation was lower in the summer than in an average year (Fig. 1).

Four annual forage crops were used for this experiment. They were oats (*Avena sativa* L. cv. Qingyin-1), forage-type triticale (×*Triticosecale Wittmack* cv. Dongsi-1), common vetch (*Vicia sativa* L. cv. Ximu-324) and naked barley (*Hordeum vulgare* L.cv. Kunlun-12). The oats, common vetch and naked barley used in this experiment were produced in Xining, Qinghai province, China, while the forage-type triticale was produced in Harbin, Heilongjiang province, China. Naked barley was used as a control group in this experimental design.

### Productivity of Single and Sequential Cropping of Oats, Forage-type Triticale and Naked Barley

Treatments consisted of single cropping and sequential cropping of oats, forage-type triticale and naked barley. The experimental design was a completely randomized block with 6 treatments and 3 replicates. The individual plot size was 2 m × 3 m. Walkways with a width of 50 cm were set in order to divide each plot and surrounding areas. The plots were irrigated prior to sowing with 6000 $m^3$ $ha^{-1}$and were fertilized with 225 kg DAP (diammonium phosphate) and 150 kg urea (each containing 6.6 kg N + 45 kg $P_2O_5$ and 69 kg N, respectively) per ha. Seeds of each individual forage species were sown on 30April, 2009 for both single and sequential cropping plots at the rate of 300 kg $ha^{-1}$. The same amount of urea was applied as a supplement on 6 June during the rapid shoot growth period, and the plots were irrigated at both the jointing and heading stages.

The first crop of the sequential cropping plots was harvested at the milk-ripening stage (13 July), and the second crop was reseeded on 16July and harvested on 21September, when the growing crops were at the stage of active leaf elongation without floral development. The irrigation and application of urea were repeated for the second crop in the same manner as for the first crop. Single cropping plots were harvested at the full-ripening stage (15 August).

### Seedling Germination and Yield Improvement of Compaction Methods of Oat, Forage-type Triticale and Naked Barley

The experiment was performed in a completely randomized block containing 6 treatments and 3 replicates. The individual plot size was 6 m × 8 m, and seeds of each forage species including oats, forage-type triticale and naked barley were sown on 1May, 2009. After sowing, two covering methods were utilized, including the traditional plowing technique and a roller compaction treatment. Traditional plowing (commonly applied for barley cultivation in Tibet) was conducted with a tooth-equipped board that was pressed by a man standing on it and was drawn by cattle (Fig. 3a). After the traditional plowing method was conducted, a landroller was used to compact the soil (Fig. 3b). The other field management measures were identical to that of the single cropping experiment.

Meanwhile, an additional trial area without a roller compaction treatment was also prepared in the experiment field for each of the three crops in three replicates (plot areas were 6 m × 8 m for each), and the germination and yield were compared to that of the corresponding crop with roller compaction.

### Yield and Quality Improvement in Oats by Mixed-sowing with Common Vetch

Both oats and common vetch (abbreviated as O and V, respectively) were seeded as single crops (control) at rates of 300 and 75 kg $ha^{-1}$, respectively. For the mixed-cropping plots, oats and common vetch were mixed at seeding rates of 100, 95, 90, 85, 80, 75 and 70% of each corresponding seeding rate in the control. The seeding ratio in each of intercrops was abbreviated as A, B, C, D, E, F and G for oats and 1, 2, 3, 4, 5, 6 and 7 for common vetch, respectively, in decreasing order from 100-70%. Thus, in plots A1, D4, and G7, for instance, the oat and common vetch seeds were mixed using the rates of 100, 85 and 70% of pure stands, respectively. The experiment was conducted in 3 replicates on 51 plots in total, each with an area of 3 m × 2 m Walkways with a width of 1 m were prepared to divide the plots and surrounding areas.

The plots were irrigated prior to seeding, and a basal dressing (225 kg DAP and 150 kg urea/ha) was applied after the soil dried. Seeds were sown on 1May, 2009. The row spacing was 20 cm and the seeds were mixed and sown together. Urea was also administered on 6June (the jointing stage of oats), and the plots were irrigated at both the jointing and heading stages. Forage was harvested on 27 August, when the common vetch was at the initial bloom stage.

### Measurement of Forage and Crude Protein Yields

The yield of fresh forage was measured in 1×1 m square quadrants set in each replicate of plots. Soon after the measurement, the fresh materials were transferred to a large storage house that was fully ventilated for the entire day (air humidity was quite low) and was spread for drying with frequent agitation. The hay yield was determined when the water content decreased to 17±2% in the fresh material. Dry matter was not determined in this study because there was no facility available for drying hay close to the site in Shigatse. The nitrogen content of the hay harvested from mixed cropping and pure stand plots was determined in the laboratory at a later date using the Kjeldhal method.

### Measurement of Germination Percentage

Germination percentage was determined by dividing the emerging seedling number counted in the 1×1 m square quadrants in each plot by the sown viable seed number per $m^2$ (×100).

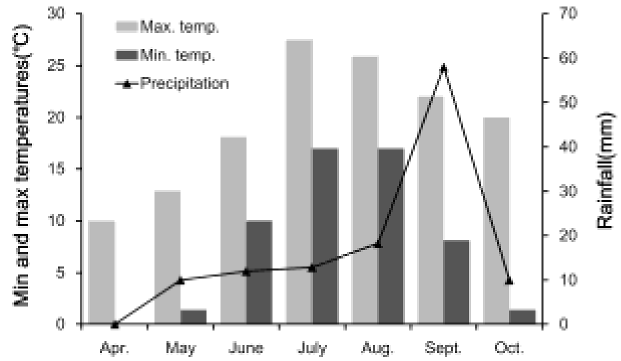


**Fig. 1:** Temperature (°C, mean maximum and minimum monthly temperature) (bar) and precipitation (mm) (line)in Shigatse during the growing season of 2009. Source: Shigatse Meteorological Station

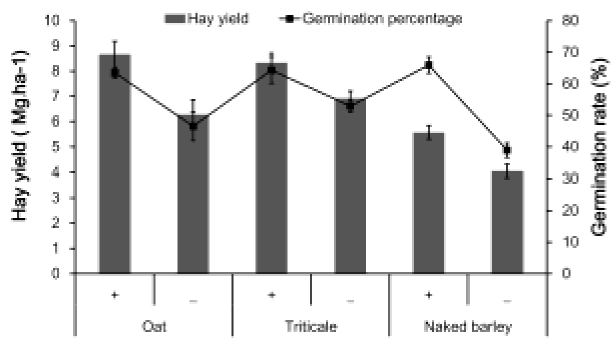


**Fig.2:** The effect of compaction treatment on germination (line) and hay yield (bar)under single cropping. + and -, with and without roller compaction. Seeds were sown on 30April, 2009. Average dates of germination, for oats and triticale were on 9 May with roller compaction and 6 May without roller compaction; naked barley germination was on 13 May with roller compaction and 8 May without roller compaction

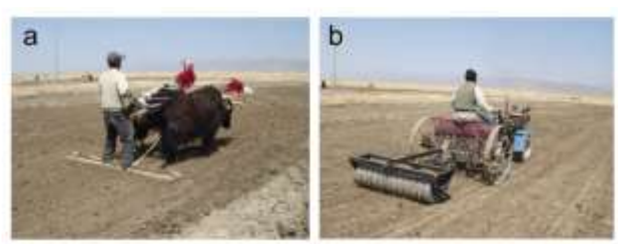


**Fig.3:** Traditional plowing and roller compaction conducted soon after seeding. (a) Traditional plowing with tooth-harrow; (b) Compaction treatment with a roller

### Statistical Analysis

Treatments in both experiments were laid out in a randomized block design and replicated three times. All data were statistically analyzed by ANOVA and treatment means

**Table 1:** Plant height and hay yield at each harvest for single and sequential cropping

| Items | Crops | Single cropping[b] | Sequential cropping | | |
|---|---|---|---|---|---|
| | | | First harvest[b] | Second harvest[b] | Total |
| Plant height (cm)[a] | Oats | 135.0±2.5 Ba | 109.5±1.1 Ca | 74.1±2.5 Da | 183.6± 2.7 Aa |
| | Triticale | 124.7±2.1 Bb | 94.4±2.4 Cb | 67.8±1.2 Db | 162.2 ± 1.2 Ab |
| | Naked barley | 77.5±2.7Ac | 45.5±1.7Bc | -[c] | 45.6 ± 1.7 Bc |
| Hay yield ($Mg.ha^{-1}$)[a] | Oats | 8.67 ± 0.5Ba | 6.67 ± 0.3Cb | 5.75 ± 0.5Da | 12.42 ± 0.5 Aa |
| | Triticale | 8.33 ± 0.3 Ba | 7.25 ± 0.2Ca | 3.58 ± 0.1 Db | 10.8 ± 0.3 Ab |
| | Naked barley | 5.57 ± 0.2Ab | 3.82 ± 0.1 Bc | - | 3.82 ± 0.1 Bc |

[a]Values indicate means ± standard errors (n=3).Each different capital letters in the same row and different lower case letters in the same column indicates the significant difference among the treatments and the crops, respectively (P<0.05)
[b]Harvest date of oats, triticale and naked barley at the ripe stage in single cropping and at the milk ripe stage for the first harvest in sequential cropping; the oats were at the heading stage and the triticale was at the jointing stage at the time of the second harvest in sequential cropping
[c]The data could not be measured due to non-emergence of naked barley as the second crop in sequential cropping

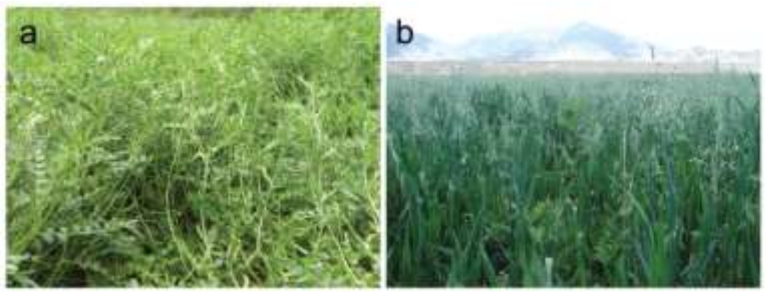


**Fig. 4:** Growing canopies of pure common vetch and mixed stands of oats and common vetch. (a) Common vetch became established in a pure stand with a lower canopy height; (b) Both oats and vetch grew in a tall, dense canopy in mixed stands, even at the time of harvesting

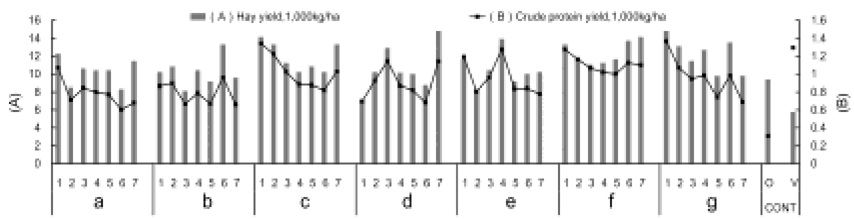


**Fig.5:** The effect of a mixed ratio of oats and common vetch on hay yield (bar) and crude protein yield (line). (a,b,c,d,e,f and g)denote the ratios of oats, from 100, 95, 90, 85, 80, 75 and 70%, respectively. 1, 2, 3, 4, 5, 6 and 7 denote the ratio of common vetch, from 100, 95, 90, 85, 80, 75 and 70%, respectively. (o and v) stand for oats and common vetch, respectively

were compared using the least significant differences (LSD) at the P<0.05 level of probability.

## Results

### Evaluation of Oats and Forage-type Triticale in Sequential Cropping

The plant height of oats was significantly higher than that of forage-type triticale in each cropping plot, where as naked barley was the lowest among the crops examined (P<0.05) in Table 1. In the single cropping plot, the order of plant height was oats > forage-type triticale > naked barley(P<0.05). In the sequential cropping plot, the plant heights of the first harvest of both oats and forage-type triticale were significantly higher than that of the second harvest (P<0.05). The total plant height of oats and forage-type triticale in the sequential cropping plot was 35.99and 30.07% higher than that of the single cropping plot, respectively. However, the plant height of naked barley was reduced by 41.31%, which was due to the fact that the naked barley in the sequential cropping plot had no seed germination after being reseeded, and the advantages of first harvest season for the plants' rapid growth led to the total plant height of sequential cropping being lower in the second season than for single cropping.

The hay yield of both oats and forage-type triticale was significantly greater than that of naked barley in the single cropping system (P<0.05). Although oats presented the highest value, no significant difference was found the yields of oat and forage-type triticale. In sequential cropping, the yield of the first harvest of both oats and forage-type triticale was significantly higher than that of the second harvest, though it stayed lower than that of single cropping ($P<0.05$). The second harvest of oats revealed a fairly high yield, which approached 86% of the first crop; thus, the sequential cropping of oats resulted in the highest yield (12.42Mg $ha^{-1}$ hay) in total, which was 43% higher than that of single-cropped oats. Although the yield of the second crop of sequential forage-type triticale was not as high as that of oats, the total yield exceeded the single crop (30% higher) as well.

**Effect of Compaction Treatment on Seedling Emergence and Further Growth**

Although the seedling emergence of oats, forage-type triticale and naked barley was slightly delayed by additional compaction conducted soon after traditional plowing (delayed by 3, 3 and 6 days, respectively), the germination percentage significantly increased for oats, forage-type triticale and naked barley by 18, 8and 30%, respectively ($P<0.05$), as seen in Fig. 2. Contrarily, a high percentage of the seedlings in plots subjected to traditional plowing only did not survive through the young seedling stage.

**Improvement of Forage Yield and Crude Protein Content by Incorporating Common Vetch**

Of the combinations examined, the highest yield, with nearly 15.0Mg $ha^{-1}$, was observed in treatments D7 (85% oats + 70% common vetch) and G1 (70% oats + 100% common vetch) in Fig. 5. Compared to singly cropped common vetch and single stand oats, the yield of D7 and G1 was increased 58 and 155%, respectively.

The highest crude protein yield was obtained from mixture group G1 (70% oats + 100% common vetch) in Fig. 5, which was 1513.06 kg $ha^{-1}$. Compared to singly cropped common vetch and single stand oats, the crude protein yield of G1 was increased 414.91 and 16.77%, respectively.

## Discussion

The Shigatse area of Tibet is characterized by the rain shadow of the Himalayas with high altitudes and low latitudes, which produces cooler, moderate summer seasons with a sizable amount of rainfall (Fig. 1) and rich drainage of the Yarlung Zangbo River for crop cultivation. Due to their similar growth characteristics to naked barley, matured crops of oats and forage-type triticale grown in Shigatse should be harvested in mid-August (fully ripening stage) when cultivated in a single cropping system. In this cropping system however, a two-month gap that is suitable for crop growth is not fully utilized for forage production, as the first frost does not occur until mid-October in this area. This summer period is actually rather favorable for the growth of temperate grass plants because the temperature often goes beyond 20°C in day time and does not drastically drop at night, and precipitation in the region is suitable for retaining soil humidity in an average year (Fig. 1).

In the case of sequential cropping examined in this experiment, the first crops of oats, forage-type triticale and naked barley were harvested in mid-July, when plant maturity was at milk-ripening stage. Accordingly, a period of almost three months between the first harvest and the first frost was available for growth of the second crop, possibly resulting in sufficient second crop growth and an increased yield of oats and triticale (Table 1). Although the primary growth of spring-sown oats appeared to be lower in Tibetan agricultural regions compared to those grown at high altitudes (Martineza *et al.*, 2010), the yield was nearly equivalent to that observed in single-cropped lowland areas when combined with the second crop (Table 1). The data observed in this study suggested that the introduction of oat and forage-type triticale in a sequential cropping system would be the most effective way to improve annual forage production in the Shigatse area. In contrast, when naked barley was used as the second crop in sequential cultivation, this crop did not germinate under the same experimental conditions. The reason for this was unclear, but naked barley seeds often fail to sufficiently germinate at higher temperatures under conditions of strong sunshine and reduced soil humidity. Thus, this crop appears to be unsuitable for sequential cropping for forage production in the variable weather conditions often observed in the river valley regions of Tibet.

The reduction in seedling establishment appeared to be due to insufficient soil compactness caused by the lack of roller treatment. This would lead to high water evaporation rates and inefficient solid root penetration, such as the formation of hanging roots. However, when an additional compaction treatment was conducted after plowing, hanging roots and seedling death were not observed. Thus, the hay yield of oats, forage-type triticale and naked barley became significantly greater ($P<0.05$) when an additional compaction treatment was performed after traditional plowing, showing increases of 37.93, 20.48and 37.45%, respectively compared to those observed after traditional plowing (Fig. 2). Therefore, an additional soil compaction step should be included during annual forage cultivation in this area, where light irradiation is extraordinary high and evaporation from the soil surface occurs very quickly.

Seedlings of both oat and vetch started fairly active growth regardless of the mixtures used. Because of its lodging habits, common vetch is unable to perform erect growth and tends to form a creeping canopy (Fig. 4a), which results in lower productivity than observed with erect legumes. However, in a mixed cropping system, the vetch easily climbs accompanying oat plants and is capable of wider vertical distribution, forming a denser and taller mixed grasses canopy (Fig. 4b) (Robinson, 1969; Thompson *et al.*, 1992).

Of the combinations examined, the highest yield was D7 and G1 with nearly 15.0 Mg $ha^{-1}$(Fig. 5). Generally, the yield increased in most of the mixed cropping systems when compared to the pure oat population. The yield of pure vetch stand was quite low (60% of pure oat yield). The yield of a mixed sward containing high (A) and low yielding crops (B) is commonly lower than that of pure A and higher than that of pure B stands, respectively. However, in some minor cases of mixed culture trials containing grass crops and vetches, the yield of the grass-vetch mixture often exceeded that of the pure grass stand (Carr *et al.*, 2004; Dhima *et al.*, 2007). As described above, this study provided similar results: combination with vetch, which was not very productive in a pure stand, did not severely reduce the productivity of the oat crop (Fig. 5). This suggests that vetch plants are not very competitive against accompanying grass crops and actually seem to be rather cooperative, which is likely due to their specific lodging growth pattern, which allows for efficient vertical arrangement of shoot organs of both species (Caballero *et al.*, 1995; Lithourgidis *et al.*, 2006). The same advantage in mixture has also been found in cultivation of other cereals intercropped with climbing beans (Caballero *et al.*, 1996). In spite of the cooperative effects of vetch, we could not find a clear increase in yield for differential combinations of oats and common vetch. The reason for this unclear yield effect is likely caused by the narrow mixing ratios applied in this experiment.

Treatment G1 (1,513 kg $ha^{-1}$) presented the highest crude protein yield, which was more than three times higher than that of single stand oats and was even higher than that of singly cropped common vetch (Fig. 5). These results again confirm that mixed cropping generally produces more yields per area than its respective pure stands (Banik *et al.*, 2000; Park *et al.*, 2002). As the crude protein content decreases with reduction in the seeding rate of common vetch, a higher rate of vetch density is recommended to maximize crude protein yield. Although the seeds in the G1 treatment cost 90 Yuan $ha^{-1}$ more than in D7 in this experiment, the G1 treatment produced 228 kg $ha^{-1}$ more crude protein than D7, so this particular combination still provides proper economic benefits.

In conclusion, in Shigatse, China, oats and forage-type triticale revealed distinctly higher productivity than naked barley for forage cultivation. The yields of both of these crops were enhanced by sequential cropping by 43 and 30%, respectively compared to single cropping. On the contrary, sequential cropping seemed to be unsuitable for the naked barley, because of its very low germinating ability in summer seasons with intense sunlight. Additional roller compaction after traditional plowing was essential for this increase, as it dramatically increased the seedling emergence and hay yield. The mixture of vetch and oats is a better way to introduce oats for forage cultivation in Shigatse. The mixture of common vetch with oats at the 70% oats + 100% common vetch seeding ratio achieved the highest forage yield and protein content of the mixtures studied.

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