Responses of Old-field Vegetation to Spatially Homogenous or Heterogenous Fertilisation: Implications for Resources Utilisation and Restoration

ABSTRACT: Availability and heterogeneity of resources have a strong influence on community biomass and diversity, which provided a valuable opportunity to evaluate the responses of vegetation on fertilization, to test whether fertilization can accelerate vegetation restoration in infertile lands.

In loess hilly region of China, most newly abandoned infertile lands often undergo heavy soil erosion. It is urgent to promote the restoration of these types of lands. As availability and heterogeneity of soil nutrients have a strong influence on plant community, we conducted a fertilisation experiment with three-factor treatments, to test whether fertilisation can promote the biomass and species richness of an Artemisia scoparia-dominated old field community. The three factors were: spatial patterns (homogeneity and heterogeneity), levels (low, medium and high), and scales (three levels with small, intermediate, and large patches) of fertiliser application. Above- and below-ground biomass and species richness were recorded. The responses of the plant community to the three factors were evaluated and compared with those of the control (no fertilisation). The results show that: (1) The application of fertiliser in either homogeneous or heterogeneous pattern significantly increased the above-ground and below-ground biomass of the plant community as compared with the control. (2) In heterogeneous conditions, the above-ground biomass in nutrient-rich patches was significantly greater than the expected value of 50%. Under intermediate and large scales of the low level and all scales of the medium and high levels, the proportion of 0–15 cm below-ground biomass was also significantly greater than 50%. (3) Both homogeneous and heterogeneous fertilisation greatly increased community richness as compared to the control. Fertilisation, particularly heterogeneous fertilisation, can effectively increase community biomass and diversity. Under patchy habitat, it seems that the responses of vegetation to heterogeneous fertilisation are related to the patches scale and the contrast among patches, nutrient usage efficiency, edge effects on plant and soil, and plant competition are responsible for the responses. The results also suggest that heterogeneous fertilisation should be applied widely in infertile old fields to accelerate secondary succession.

KEY WORDS: above-ground biomass, below-ground biomass, fertilisation, nutrient heterogeneity, old field, species richness, resource competition, patchy habitat

1. INTRODUCTION

The heterogeneity of resources has a strong influence on plant community structure and biomass (Baer et al. 2004). As varied community species have root systems with different physio-ecological traits, they
may respond differently to heterogeneous conditions with different patch scales and contrasts. The responses to such conditions are mainly reflected by possible increases in nutrient uptake (Robinson 1994, Schottelndreier and Falkengren-Grerup 1999), increases in root proliferation in nutrient-rich patches (Robinson 1994), and associations between root magnitude and patch scales (Grime 1994, Schwinning and Weiner 1998). Thus, heterogeneity in nutrient distribution is expected to affect the structure and even the yield and spatial distribution of biomass in a community. Furthermore, the rate and pattern of succession may also be associated with the spatial distribution and availability of soil resources (Glenn-Lewin and van der Maarel 1992, McCook 1994). During succession, the cluster distribution of plants, formation of fertility islands, and other chronic disturbances are common, all of which can alter the availability and/or spatial distribution of resources (Robertson et al. 1988, Robertson et al. 1993, Rover and Kaiser 1997). These can in turn strongly influence the vegetation pattern and community structure of a terrestrial ecosystem (Grime 1979, Huston 1979, Tilman 1984, 1987, Stevens and Carson 2002). Given its key role in natural systems, resource heterogeneity seems to control the rate and direction of community restoration. Although plant communities can recover from disturbances through natural succession, many aspects of the community structure return slowly in the absence of human intervention (Pywell et al. 2002). Thus, steering the rate and direction of recovery is a fundamental aspect of restoration ecology, and restoration presents a valuable opportunity to test ecological theories on community recovery following disturbance (Bradshaw 1987, Ewel 1987, Hobbs and Norton 1996, Palmer et al. 1997). At the onset of grassland restoration in formerly cultivated soils, however, the availability and spatial distribution of resources may not be representative of uncultivated (native) grassland. Therefore, the re-establishment of heterogeneity and improvement of fertility may redound to the restoration of abandoned land.

In the Loess Plateau region of China, soil and water loss is very severe in the old fields of tablelands and slope lands due to the low ground cover and loose topsoil in the region.

Restoration of these old fields – as well as the similar type of deprived areas that undergo severe erosion like the sub-humid and semiarid regions of sub-Saharan Africa, the Andean region, Haiti and the Caribbean, etc., is urgent, especially that restoration of community biomass and coverage is important for the control of soil erosion. In the past, little fertilisation was applied to these types of farmland during long-term cultivation, making the newly abandoned fields uniform and low in fertility (Table 1). Severe soil erosion further aggravates the soil nutrient status of these types of farmlands. As natural restoration is relatively slow under an infertile condition, fertilisation is needed to accelerate re-vegetation.

In this study, we altered the availability and heterogeneity of soil fertility in a newly abandoned old-field community (dominant species: Artemisia scoparia Waldst. et Kit.) through fertilisation, to test the following predictions: (1) If fine root turnover or nutrient uptake is increased under heterogeneous conditions, then the community biomass may be greater in heterogeneous conditions than in homogeneous conditions given the same nutrient level; (2) if there are selective root placement and proliferation in nutrient-rich patches, the community structure indexed by biomass distribution may change as more above-ground and below-ground biomass is placed in nutrient-rich patches; and (3) the appropriate scale of heterogeneous fertilisation for plants to respond to may be related with the root system magnitude. If the scale is too large, plants may

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Organic matter (%)</th>
<th>Total nitrogen (%)</th>
<th>Total phosphorus (%)</th>
<th>Total potassium (%)</th>
<th>NH4-N (mg kg⁻¹)</th>
<th>NO3-N (mg kg⁻¹)</th>
<th>Available phosphorus (mg kg⁻¹)</th>
<th>Available potassium (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–20</td>
<td>0.48(1.53)</td>
<td>0.031(0.082)</td>
<td>0.058(0.056)</td>
<td>2.08(2.08)</td>
<td>11.05(13.70)</td>
<td>0.87(1.68)</td>
<td>4.12(3.32)</td>
<td>77.00(99.20)</td>
</tr>
<tr>
<td>0–40</td>
<td>0.43(0.54)</td>
<td>0.026(0.029)</td>
<td>0.057(0.051)</td>
<td>2.07(2.12)</td>
<td>9.98(10.53)</td>
<td>0.65(0.79)</td>
<td>2.40(2.85)</td>
<td>64.20(46.95)</td>
</tr>
</tbody>
</table>
not be able to detect the nutrient difference and respond actively by proliferating roots in nutrient-rich patches. If the scale is too small, the nutrient patch may easily become uniform within a short time because of migration and plant abortion (i.e., there is not enough time for plants to respond). We also predict the followings with regard to patch size: (i) There will be an appropriate patch size to which the community structure acts sensitively to heterogeneous conditions, and (ii) community biomass will increase as the patch size or nutrient difference between patches increases to some extent.

2. SITE DESCRIPTION

The study site is located in Gaoqiao town (county) (36°39’N–109°11’E, altitude ranging from 1,050 to 1,380 m) of Shaanxi Province, China, belonging to a typical hilly region of the Loess Plateau. The soil is loess in nature. The region typifies the continental climate, with warm, rainy summers and cold, dry winters. The annual precipitation regime is characterised by a unimodal distribution pattern, with a peak occurring from June to September. This contributes to about 70% of the annual precipitation and to a dry season between November and May. During the past 35 years, the mean annual temperature has ranged from 7.7 to 10.6°C and precipitation has ranged from 490.5 to 663.3 mm. The annual average frost-free period is around 157 days. The annual land use system in this area is short fallow agriculture with two ploughs in the spring. The experimental site sits on a tableland. The site soil is degraded due to soil erosion and long cultivation (about 50 years) without fertilisation; therefore, its nutrient level is relatively low (Table 1). This area is devoid of any dominant “native” vegetation because it has been opened up and cultivated for food supply in the past. Now, the dominating herb species in the loess hilly area are Lespedeza davurica (Laxm.) Schindl., Bothriochloa ischaemum L. Keng, and Artemisia giraldii Pamp., which appear in the later succession stage.

3. METHODS

3.1. Experimental design

The experiment was carried out in an Artemisia scoparia Waldst. et Kit. –dominated old-field community located in a tableland that has been abandoned for six years. A. scoparia is an annual or biennial herb that emerges in June and dies back in September or October. This species usually dominates communities of early old fields in the Loess Plateau. In April 2005, the beginning of the growing season, nutrients were applied in the form of ordinary compound fertiliser (GB15063-2001, N:P2O5:K2O≈1:1:1, about
54% in total, Huayang Chemical Industry) in either spatially heterogeneous or homogeneous pattern arrangements. Three nutrient levels, denoted as low, medium, and high, corresponding to 30, 50, and 70 g of application per square metre, respectively, were applied in both heterogeneous and homogeneous treatments. It should be noted that 50 g compound fertiliser per square metre is roughly the mean of the local generalized application level on terrace lands. In heterogeneous treatments, chequerboard layout was used to create nutrient-rich and nutrient-poor patches. Each chequerboard was divided into 16 cells in four rows and four columns. Each treatment contained equal numbers of nutrient-rich and nutrient-poor cells occupying the same area. Each cell was allocated a unique number to define its location (Fig. 1). There were three patch sizes or scales for heterogeneous treatments. In the large patch treatment, the chequerboard measured 4 × 4 m, and each cell measured 1 × 1 m. In the intermediate and small patch treatments, the chequerboards had dimensions of 2 × 2 m and 1 × 1 m, and the cells measured 0.50 × 0.50 m and 0.25 × 0.25 m, respectively. The smallest cell size of 0.25 × 0.25 m is about the root system magnitude of the dominant species A. scoparia (Du et al. 2007a). The homogeneous treatment and control were designed to include the same number of cells and the same size of scales (Fig. 1), but all the cells assigned for homogeneous treatment were applied the same amount of fertiliser. The control was located in an ambient natural community without any fertiliser applied. In the three heterogeneous treatments, nutrient-poor cells received no fertiliser. Therefore, the amounts of fertiliser in each nutrient-rich patch (or cell) in the low-, medium-, and high-nutrient levels were 3.75, 6.25, and 8.75 g for small-scale heterogeneous treatment; 15, 25, and 35 g for intermediate-scale heterogeneous treatment; and 60, 100, and 140 g for large-scale heterogeneous treatments, respectively. For homogeneous treatments, fertiliser was applied to the whole treatment plot. The amounts at low, medium, and high levels were 30, 50, and 70 g in the small scale; 120, 200, and 280 g in the intermediate scale; and 480, 800, and 1,120 g in the large scale, respectively. Each treatment was comprised of six replicates and was arranged in a fully randomised design. Community investigation and harvesting were carried out in September 2007. In all treatments, the individual numbers of every species in all cells were recorded. For heterogeneous treatments, cell numbers 4, 7, 10, and 13 were selected from nutrient-rich patches, and cells numbers 1, 6, 11, and 16 were selected from nutrient-poor patches. These cells were chosen for harvesting and weighting of above-ground biomass (Fig. 1). For homogeneous treatments and the control, the same cells were harvested. Below-ground biomass was sampled at the centre of several cells with soil augers (the auger head is 10 cm in diameter and 15 cm in length), down 105 cm at 15 cm intervals. The sampled cells were numbers 7 and 10 in nutrient-rich patches and numbers 6 and 11 in nutrient-poor patches (Fig. 1). The soil samples, including roots obtained, were sieved, and the crude root samples were weighed after cleaning and air drying.

3.2. Data analysis

All data were analysed using SPSS version 16.0 for Windows (generalised linear model procedure, SPSS Inc.). For each treatment, the above-ground biomass measurements from the eight cells were summed up and averaged to determine the community per unit area of above-ground biomass; the below-ground biomass measurements from the four cells were also summed up and averaged. The effects of treatments on biomass were analysed by univariate analyses of variance (ANOVA) with levels, spatial patterns, and scales of fertilisation as the fixed factors, and above-ground and below-ground biomass as the dependent variables.

To determine whether heterogeneous fertilisation pattern affects the spatial pattern of biomass distribution, the proportion of above-ground biomass and below-ground biomass in 0–15 cm, 16–30 cm, 31–45 cm, 46–60 cm, 61–75 cm, 76–90 cm, and 91–105 cm layers harvested from nutrient-rich patches was compared to an expected value of 50% (nutrient-rich patches occupied 50% of the experimental area) using the one-sample t-test.

As the sampling area at different scales greatly influences species diversity, the species rarefaction curves of each fertilisation
treatment were analysed and plotted (referred to Chao 1987). We used species richness at the flat position of the rarefaction curves to analyse the effects of treatments on diversity by univariate ANOVAs, with spatial patterns, levels, and scales of fertilisation as the fixed factors and richness as the dependent variable.

4. RESULTS

4.1. Above-ground and below-ground biomass

ANOVA revealed that fertilisation patterns significantly improved both above-
ground and below-ground biomass of the community (Table 2). For the heterogeneous fertilisation, each unit area of the above-ground (281.0 ± 134.9 g m⁻², \( P < 0.001 \)) and below-ground (168.6 ± 65.9 g m⁻², \( P < 0.001 \)) community biomass showed an increase of 155% and 294%, respectively, against the control (110.1 ± 53.9 and 42.8 ± 12.3 g m⁻²). For homogeneous fertilisation, the increases were 109% and 168%, for the above-ground community (230.1 ± 96.3 g m⁻², \( P < 0.001 \)) and below-ground community (115.0 ± 43.4 g m⁻², \( P < 0.001 \)), respectively (Fig. 2). Fertilisation levels and scales, and their interaction of patterns, levels, and scales had no significant ef-

![Graph](image_url)

**Fig. 2.** Per unit areas of above-ground (A) and below-ground (B) biomass in homogeneous and heterogeneous treatments at small (S), intermediate (I), and large (L) scales of fertilisation. Per unit areas of above-ground biomass in control are presented at the corresponding sampling scales. See Table 2 for associated analyses.
Table 2. Effects of fertilisation patterns, levels, and scales on per unit area of above-ground and below-ground biomass and species richness. The table shows the results of the three-way univariate ANOVAs with per unit area of above-ground and below-ground biomass and species richness as the dependent variable, and patterns (P), levels (L), and scales of nutrient supply (S) of fertiliser application as the independent variables. d.f. = degree of freedom, MS = mean square. See Figs. 2 and 5 for means and standard errors.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Above-ground biomass</th>
<th>Below-ground biomass</th>
<th>Species richness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>F</td>
<td>P</td>
<td>F</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>5.416</td>
<td>0.022</td>
<td>15.485</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>0.858</td>
<td>0.427</td>
<td>1.420</td>
</tr>
<tr>
<td>S</td>
<td>2</td>
<td>0.779</td>
<td>0.461</td>
<td>0.134</td>
</tr>
<tr>
<td>P×L</td>
<td>2</td>
<td>0.913</td>
<td>0.405</td>
<td>0.030</td>
</tr>
<tr>
<td>P×S</td>
<td>2</td>
<td>0.419</td>
<td>0.659</td>
<td>0.040</td>
</tr>
<tr>
<td>L×S</td>
<td>4</td>
<td>0.341</td>
<td>0.850</td>
<td>0.064</td>
</tr>
<tr>
<td>P×L×S</td>
<td>4</td>
<td>0.350</td>
<td>0.844</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Fig. 3. Mean (+1 SE) proportion of above-ground biomass and 0–15 cm below-ground biomass located in nutrient-rich patches at small (S), intermediate (I), and large (L) scales of heterogeneous fertilisation treatments. * >0.05, ** >0.01.

4.2. Pattern of biomass distribution

In the heterogeneous treatments, the mean proportion of the above-ground biomass from nutrient-rich patches ranged from 51% (large scale, low-fertilisation level) to 77% (large scale, high level); the values of below-ground biomass ranged from 58% (small scale, low level) to 66%. (large scale, medium level). At the medium level of all scales and high levels of intermediate and large scales of heterogeneity, nutrient-rich patches contributed more significant above-ground biomass than the expected 50% (Fig. 3). Except for the low level of small-scale treatment, other heterogeneous fertilisations had significant effects on the distribution of the 0–15 cm layer below-ground biomass; no significant effects were found in the distribution of other layers. At 0–15, 16–30, 31–45, 46–60, 61–75, 76–90, and 91–105 cm layers of all heterogeneous fertilisation treatments, the mean percentages of below-ground biomass from the nutrient-
Response of vegetation on spatial pattern of fertilisation

Fig. 4. Species rarefaction curves of fertilisation treatments.
rich patches were 62, 54, 51, 49, 52, 52, and 48% of the total biomass at the corresponding layers, respectively. It would seem that heterogeneous fertilisation has a greater effect on the distribution of belowground biomass in the top layer than that in lower layers.

4.3. Species diversity

The rarefaction curves showed that either heterogeneous or homogeneous fertilisation could obviously increase species richness, and the level of richness resulting from heterogeneous fertilisation was slightly higher than that resulting from homogeneous treatment (Fig. 4). When 100 individuals of a community species were sampled, the rarefaction curves were flat, and the effects of sampling area on species diversity could be considered removed. At this position, the average species richness of heterogeneous fertilisation, homogeneous fertilisation, and control were 13.7, 10.8, and 7.3, respectively. ANOVAs revealed that patterns of fertilisation had significant effects on species richness (Table 2). No significant effects were found between scales or levels of treatments (Fig. 5). Levels of fertiliser application had more effects on species richness than scales (Table 2).

5. DISCUSSION

5.1. Improvement of community biomass under heterogeneous fertilisation

Many studies have shown that plants select more favourable patches of heterogeneous substrates in which to place their roots and that significant root proliferation occurs in nutrient-rich patches, sometimes at the expense of root growth in nutrient-poor patches (Robinson 1994, Wijesinghe and Hutchings 1997, Fransen et al. 1998, Einsmann et al. 1999, Robinson et al. 1999, Wijesinghe and Hutchings 1999). Plants that display such selectivity in root location, as well as root proliferation in more favourable patches of substrate, enhance their acquisition of nutrients, particularly in the presence of competitors (Robinson et al. 1999). The acquisition of nutrients can be achieved more efficiently when the same amount of nutrients is concentrated into a smaller volume of the available substrate than when it is uniformly distributed (Kovar and Barber 1989, Jackson and Caldwell 1996). These facts suggest that essential resources can be acquired faster under heterogeneous conditions, resulting in greater growth, at least until the supply of resources becomes exhausted (Day et al. 2003). Day et al. (2003) observed significant yield benefits after 31 days in populations of *Cardamine hirsuta* grown under heterogeneous conditions compared with populations in homogeneous conditions with the same overall level of nutrient supply. In our case, the above-ground and below-ground biomass of *Artemisia scoparia* community also significantly benefited from heterogeneous fertilisation (e.g., as compared to homogeneous fertilisation at the same overall level of fertiliser). To demonstrate, the above-ground biomass under heterogeneous conditions achieved 17, 13, and 28% improvements at low, medium, and high levels of fertilisations, respectively. These improvements may be the result of increased nutrient acquisition efficiency brought about by heterogeneous fertilisation.

5.2. Pattern of biomass distribution is related with patches scale and contrast

Not all studies, however, have revealed increased growth under heterogeneous con-
ditions (Casper and Cahill 1996). In such cases, it is possible that the scale of heterogeneity used to determine the responses of the investigated species were inappropriate (Wijesinghe et al. 2001, Hutchings et al. 2003), or the differences between nutrient-rich and nutrient-poor patches to which plants respond were not large enough.

As predicted, most proportional items of both above-ground and top layer of below-ground biomass located in nutrient-rich patches were observed significantly greater than the expected value of 50% (Fig. 3), which may be the reason for biomass improvements under heterogeneous fertilisation compared with homogeneous ones. This pattern of biomass distribution under heterogeneous fertilisation can be ascribed to the edge effect on plant response. In heterogeneous habitat, both below and above-ground parts in nutrient-rich patches have chance to gain light and water from unfertilized patches, so plants at the edge can avoid competition by lateral growth to some extent.

We found that both per unit area of above-ground and belowground biomass (Fig. 2), and the proportion of biomass located in nutrient-rich patches (Fig. 3), were relatively smaller at the small scale as compared to those at the intermediate and large scales under heterogeneous fertilisation. These findings may be attributed to the following possible counteractive effects: (1) In our case, the patch size of small scale was designed to be approximately equal to the magnitude of the Artemisia scoparia root system (two sided root spread is about 0.25 m). The root systems of species located in the nutrient-rich and nutrient-poor patches were allowed to come into contact at such patch size; thus, species located in nutrient-poor patches may undergo intensive asymmetrical neighbourhood competitive suppression from the species located in nutrient-rich patches. This suppression would slow down the growth of species located in nutrient-poor patches and result in a greater biomass gap within communities between the nutrient-rich and nutrient-poor patches. (2) In heterogeneous habitat, plants in nutrient-rich patches at a small scale have more chances to gain light and water from unfertilized patches. A greater lateral growth is expected to occur at a small scale.

The above two effects both can lead to a greater proportion of community biomass located in nutrient-rich patches at small scale. (3) But due to plant absorption (Kleb and Wilson 1997), lateral nutrient mobilisation and the edge effect on soil nutrient, the contrast between nutrient-rich and nutrient-poor patches can easily disappear in small scale treatments, especially when the difference between nutrient-rich and nutrient-poor patches is not great enough at the small scale of low heterogeneous fertilisation. All these can cause easy disappearing of nutrient-rich patches, and shorten the time for plants to respond actively to the small nutrient-rich patches at the small scale. This phenomenon may also lead to little or no biomass improvement (Fig. 2). In addition, if nutrient acquisition is actually responsible for biomass increase under nutrient heterogeneity, smaller patches probably are not likely to stimulate plants to increase the nutrient acquisition efficiency and to proliferate more roots in nutrient-rich patches (Fig. 3).

5.3. Diversity changes after fertilisation

The mean levels and heterogeneity of soil resources have important implications in community development and diversity maintenance (McLendon and Redente 1992, Marrs 1993, Pywell et al. 1994, Janssens et al. 1998). A wide variety of hypotheses suggests that species diversity is determined by the average supply rates of the most limiting resources (Abrams 1995, Srivastava and Lawton 1998, Grace 1999, Stevens and Carson 1999, Morin 2000, Hubbell 2001). In the Loess Plateau, soil nitrogen and phosphorus are generally limited (Shen and Hong 2003, Zou et al. 1998). When the supply rates of these two limited mineral elements are enhanced by fertilisation, diversity may increase. In some instances, however, diversity may not always increase (e.g., if the free spatial niche is not enough for new species colonisation or if competitive exclusion occurs after fertilisation), and species diversity may not be affected or even decrease. Diversity can also be improved by the spatial heterogeneity of one or more limiting resources, which would prevent competitive exclusion and maintain high species diversity (MacArthur 1970, Grubb 1977, Nicotra et al. 1999, Kassen et al. 2000) because different species are
superior competitors in different parts of a heterogeneous environment. In our case, the heterogeneous fertilisation of soil-limited nutrients can also enhance species diversity better than the homogeneous fertilisation can to some extent. With regard to species richness, there are signs that fertilisation can accelerate succession. Three years after the fertiliser was applied, Ixeris chinensis, Gueldenstaedtia stenophylla, Polygaia tenuifolia, and Potentilla bifurca, which belong to auxiliary species in the later succession stage, were promoted in the homogeneous and heterogeneous treatments. Artemisia giralldii, a dominant species in the later succession stage, was also observed in heterogeneous treatments (Du et al. 2007b).

5.4. Implications of fertilisation on vegetation restoration and the control of soil erosion

Fertilisation has many effects on plant communities to shape their structure and improve their functions (e.g., the increase of biomass and richness revealed in our research). In the Loess Plateau, low-soil-nutrient levels and low vegetation biomass often interact as both cause and effect, especially for most tablelands and slope lands that undergo severe soil erosion. Increasing biomass through fertilisation has proven to be essential and practical for the restoration of grassland and the control of soil erosion in these lands (Wu et al. 2003). The improved biomass can increase water infiltration and decrease the splash amount and run-off. In the long term, organic matter will accumulate gradually, which may promote the formation of water stable aggregates (Caravaca et al. 2002) and biological soil crust (Bowker 2007), among others. All of these are helpful in controlling the loss of water and soil and in ameliorating soil conditions. Improved soil nutrition conditions make the recruitment of more species successful, and thus, the community composition tends to be more complex and diverse. This provides more chances for later-succession dominant species to compete against and out early-succession dominant species, succession may also be accelerated (Du et al. 2007b). As the relative competitive ability of species is strongly related to the community structure (Tilman 1982), and the latter can be influenced by the soil conditions of the local site (Briones et al. 1998, Pugnaire and Luque 2001) (especially by the level and spatial distribution of growth-limited factors), consequently we expect to favour the relative competitive ability of later succession species by promoting the nutrient conditions of the later succession stages (Jordan et al. 1988). Through the premier restoration of soil habitant, we may accelerate the restoration of community (Palmer et al. 1997).

To control the severe soil erosion of most tablelands and slope lands in hilly loess regions, comprehensive methods, such as the digging of level benches, level trenches, and fish scale pits in abandoned tablelands and slope lands, the construction of terraces and warp land dams, and fertilisation, seeding, need to be implemented. Of these, fertilisation is an important and practical way of improving soil conditions. Given several growth-limiting factors, soil nutrients are more easily controlled than other factors (e.g., water, light, etc.) through fertilisation. In addition, fertilisation is cheaper and more effective than seeding for the restoration of infertile old fields. Although native species have good annidation and high survival rate, their seeds are difficult to harvest. It has been observed that artificial grass communities established in the past are easily degraded. Thus, fertilisation should be recognised as an important method of vegetation restoration, especially for the rehabilitation of infertile lands.

As the results suggest, the same amount of fertiliser under heterogeneous application has relative better effects on vegetation restoration in infertile lands. For costs saving and pollution avoiding, heterogeneous fertilisation is recommendable when a large acreage of infertile lands is in need of restoration. In order to enhance or prolong the response of vegetation to patchy habitat, slow release fertiliser, like farmyard manure, is recommended to apply in patchy pattern, as the contrast among patches may disappear slowly.

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6. REFERENCES


