PLANTA DANINHA

SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS

SBCPD

<http://www.sbcpd.org>

ISSN 0100-8358 (print)
1806-9681 (online)

Article

Application of Plant Growth Regulators to *Stipa krylovii* in the Xilin Gol Grassland

*Aplicação de Reguladores de Crescimento em Plantas de **Stipa krylovii** em Áreas de Pastagem de Xilin Gol*

JUN, L.V.[1]
XUE-FENG, Z.[1]
ANJUM, S.A.[1,2]
JI-XUAN, S.[1]
YAN, Z.[1]
YU-FENG, D.[1]
ZOHAIB, A.[2]
ALI, I.[2]
YU, XU[1]
XIU-JUAN, H.[1]
SAN-GEN, W.[1]*

ABSTRACT - Plant growth regulators are an immense group of substances that have the ability to alter growth pattern of plants and can be used for improving plant growth and productivity. A study was conducted in the Xilin Gol grassland of Inner Mongolia, China, to ascertain the growth and biomass production of *Stipa krylovii* in response to exogenous application of different growth regulators at various concentrations viz. naphthalene acetic acid (NAA), 6-benzylaminopurine (6-BA), brassinosteroid (BR), sodium nitrophenolate (SNP) and forchlorfenuron, and gibberellic acid (GA3). Application of growth regulators significantly enhanced the growth and biomass production of *S. krylovii*. The height of vegetative shoot was enhanced mostly by the application of 100 mg L^{-1} GA3, while, height of reproductive shoot was increased by 25 mg L^{-1} 6-BA, 100 mg L^{-1} SNP + 5 mg L^{-1} forchlorfenuron and 50 mg L^{-1} SNP + 2.5 mg L^{-1} forchlorfenuron as compared to control. Fresh biomass was enhanced by the application of 0.02 mg L^{-1} BR, 10 mg L^{-1} SNP + 0.5 mg L^{-1} forchlorfenuron and 50 mg L^{-1} SNP + 2.5 mg L^{-1} forchlorfenuron. Application of 5 mg L^{-1} 6-BA and 50 mg L^{-1} SNP + 2.5 mg L^{-1} forchlorfenuron proved to be more beneficial in improving dry biomass of *S. krylovii*, as compared to control. In conclusion, exogenous application of different growth regulators improved growth and biomass production of *S. krylovii*. Furthermore, application of SNP + forchlorfenuron and 6-BA was more effective.

Keywords: growth, pastures, biomass production.

*RESUMO - Os reguladores de crescimento das plantas são um imenso grupo de substâncias que têm a capacidade de alterar o padrão de crescimento das plantas e podem ser utilizadas para melhorar o crescimento e a produtividade das plantas. Foi realizado um estudo nas pastagens de Xilin Gol, na Mongólia Interior (China), para determinar o crescimento e a produção de biomassa de **Stipa krylovii** em resposta à aplicação exógena de diferentes reguladores de crescimento em várias concentrações, a saber: ácido naftaleno acético (NAA), 6-benzilaminopurina (6-BA), brassinosteroide (BR), nitrofenolato de sódio (SNP) e forchlorfenuron, e ácido giberélico (GA_3). A aplicação de reguladores de crescimento aumentou de forma significativa o crescimento e a produção de biomassa de **S. krylovii**. Houve melhora na altura do eixo vegetativo pela aplicação de 100 mg L^{-1} de GA_3, ao passo que a altura do eixo reprodutivo foi aumentada nas concentrações de 25 mg L^{-1} de 6-BA, 100 mg L^{-1} de SNP + 5 mg L^{-1} de forchlorfenuron e 50 mg L^{-1} de SNP + 2,5 mg L^{-1} de forchlorfenuron, em comparação com a testemunha. Houve aumento da biomassa fresca com a aplicação de 0,02 mg L^{-1} de BR, 10 mg L^{-1} de SNP + 0,5 mg L^{-1} de forchlorfenuron e 50 mg L^{-1} de SNP + 2,5 mg L^{-1} de forchlorfenuron. A aplicação de 5 mg L^{-1} de 6-BA e 50 mg L^{-1} de SNP + 2,5 mg L^{-1}*

*** Corresponding author:**
<wangsg@swu.edu.cn>

Received: November 1, 2016
Approved: January 2, 2017

Planta Daninha 2018; v36:e018171373

[1] Engineering Research Center of South Upland Agriculture of Ministry of Education, College of Agronomy and Biotechnology, Southwest University Chongqing 400716, China; [2] Department of Agronomy, University of Agriculture, Faisalabad 38040, Pakistan.

Doi: 10.1590/S0100-83582018360100049

*de forchlorfenuron mostrou-se mais benéfica no aumento da biomassa seca de **S. krylovii**, em comparação com a testemunha. Em conclusão, a aplicação exógena de diferentes reguladores de crescimento melhorou o crescimento e produção de biomassa de **S. krylovii**. Além disso, a aplicação de SNP + forchlorfenuron e 6-BA foi mais eficaz.*

Palavras-chave: crescimento, pastagem, produção de biomassa.

INTRODUCTION

More than 70% of Inner Mongolia, a province of China, is covered by native grasslands, which accounts for almost 20% of China's total grassland area. The land is traditionally used for grazing, but it has now been changing from mobile to sedentary grazing systems, especially in the last 20 years. Simultaneously, the population of Inner Mongolia has increased considerably, leading to steeply increasing numbers of livestock. However, these grasslands have been deteriorated as a result of overgrazing, and the condition has been further aggravated by abiotic stresses under a prevailing climate change scenario (Wang and Gao, 2003; Liu et al., 2015). Grassland degradation is a widespread problem for Inner Mongolia's grasslands (Zhou et al., 2002). Awareness of this problem has increased in recent years ever since heavy sand storms originating from Inner Mongolia's steppes often hit Beijing in spring (Normile, 2007). Decreased plant productivity, and changes to species composition and diversity of grasslands in China are due to over-population, over-grazing, improper reclamation of cropland and climate change (Han et al., 2008; Gao et al., 2014). Xilin Gol grassland (19 million ha) is a typical semi-arid temperate steppe ecosystem in northern China which has great ecological and economic importance. Over the last decades, the fragmentation and degradation of this environment has been rapidly advanced and the total area of degraded steppe within the Xilin River Basin has been increased up to 72% from 1985 to 1999 (Tong et al., 2002). Compared to flat regions, grazing intensity was relatively low in the past, but because of the rising number of livestock, there has been an accelerated degradation of hilly grassland during the last two decades. Thus, more attention should be paid to the effects of land use on productivity and stability of grassland ecosystems.

Stipa krylovii is a perennial herbaceous grass with fibrous and tough roots, slim and erect stalk whose base is often wrapped in withered leaf sheath. It is the dominant species on the prairie of Inner Mongolia, with a high livestock feeding value (Yuan et al., 2005; Wang et al., 2008; Li et al., 2014). *S. krylovii* has adapted to arid climate by modulation of some of the physiological and ecological characteristics, hence it has strong drought and cold tolerance and it can survive under insufficient rain conditions (Xiao et al., 2013). All over the world, scientists are working on plants traits in response to overgrazing, i.e., photosynthetic physiological processes, propagation characteristics of the population, reproductive allocation measures, distribution of plant nutrients; however, in extensive overgrazing, these are not important plant traits (Wang et al., 2000; Zhao et al., 2006; Han and Zhao, 2011).

Plant growth regulators (PGRs) are widely used in modern agriculture and horticulture. Approximately 40 active ingredients are in use, applied either as a single component or as combinations. All in all, one can judge that PGRs have not only a history but also a future (Rademacher, 2015). Regulating the use of PGRs to enhance plant growth and development is an active research area of agricultural productivity. Between 5 and 10 plant hormones have been discovered. These hormones interact with one or more additional hormones through change in the level to regulate plant growth or response to stresses (Santner et al., 2009). PGRs are now the key part of agricultural and horticultural crop production because of their high effectiveness and low cost. Approximately 10,000 different compounds have been screened and tested for leaf, root and shoot growth of model plant *Arabidopsis* (Rodriguez-Furlan et al., 2016).

The effect of PGRs is very complex because of formulation type, concentration, method of application, time, location, plant species, climate, water and fertilizer, and other production measures that are closely related, and thus produce very different effects. For example, cytokinins control development and senescence; enhance plant resistance to salinity, low temperatures, and drought; act both in synergy and antagonism with other plant hormones, and play a role in the regulation of seed development, dormancy, and germination (Tassi et al., 2008; Hossain et al., 2010). The exogenously applied inorganic nutrient- or auxin-induced growth promotion was found to be associated with reduced membrane permeability, enhanced photosynthetic pigment concentration, reduced leaf Na^+/K^+ ratio, and altered activities of some key antioxidant enzymes such as dismutase (SOD) and catalase (CAT) under saline medium (Kaya et al., 2013). Forchlorfenuron is a phenyl-urea compound that causes strong cytokinin activity as a relatively new plant growth regulator. The main effect of this synthetic cytokinin is to promote cell division and cell enlargement. Therefore, it has been used extensively to increase the berry/fruit size of various kinds of fruits and vegetables (Cruz-Castillo et al., 2002; Kim et al., 2006). In China, forchlorfenuron has been registered for use on kiwi fruits, watermelons, cucumbers and grapes. Gibberellins caused excessive shoot elongation, and they are also involved in other processes, such as flowering and seed germination (Silverstone and Sun, 2000). One of the gibberellins, gibberellic acid (GA_3), accelerates and improves the yield of a wide variety of plants by increasing cell division (Asahina et al., 2002).

The aim of the present study was to quantify the response of *S. krylovii* against the foliar spray of a number of plant growth regulators, namely, naphthalene acetic acid (NAA), 6-benzylaminopurine (6-BA), brassinosteroid (BR), sodium nitrophenolate (SNP) and forchlorfenuron and gibberellic acid (GA_3) at different concentrations and to find the most appropriate PGRs for enhancing the growth and productivity of *S. krylovii* in Inner Mongolia. The results will help to find the options for the uplift of grasslands of China under changing climate.

MATERIALS AND METHODS

Site description and treatment details

The experimental site was located in Xilin Gol Grassland of Inner Mongolia (43°50’67” N, 116°10’16" E). Rainfall is most frequent from June to August, a period which accounts for about 70% of the annual precipitation. There is abundant light with 2750 annual sunshine hours. Annual sunshine percentage is 65% in the pasture growing season (April to September) of the total amount of more than 1500 hours of sunshine. As regards soil nutrient status, the total nitrogen content was at a medium level, with enough potassium, while soil organic matter contents are found in medium to high levels. Soil phosphorus contents were generally low in upper soil level.

The experiment was conducted from July to August in 2014 and was repeated in 2015. The PGRs were applied at different concentrations and water spray was applied to *S. krylovii* plants as control treatment in the morning. The second spray of PGR was applied again after a 7 day interval to exploit the full potential of PGR application. After pre-experiments had been conducted in a lab with pots or in a greenhouse, this experiment was comprised of application of different growth regulators each at three concentrations *i.e.* NAA (20, 100, 200 mg L^{-1}), 6-BA (5, 25, 50 mg L^{-1}), BR (0.02, 0.2, 2 mg L^{-1}), SNP + forchlorfenuron (10 + 0.5, 50 + 2.5, 100 + 5 mg L^{-1}), and GA_3 (10, 50, 100 mg L^{-1}) (Table 1).

The reason for using a combined treatment of SNP and forchlorfenuron but not an independent treatment of SNP or forchlorfenuron is that, according to our pre-experiment results, the combined treatment was more effective than the independent treatment.

Table 1 **-** Experimental treatments

Treatment	Concentration, mg L^{-1}		
	Low	Medium	High
CK (water)			
Naphthalene acetic acid (NAA)	20	100	200
6-benzylaminopurine (6-BA)	5	25	50
Brassinosteroid (BR)	0.02	0.2	2
Sodium nitrophenolate (SNP) and Forchlorfenuron	10 + 0.5	50 + 2.5	100+ 5
Gibberellic acid (GA_3)	10	50	100

A completely randomized block design with 5 replicates was used in the experiment. There were 80 plots (20 m x 20 each) in experimental site with 1 m gap between the adjacent plots.

Plant sampling and data collection

Plant samples were collected at 7 and 14 days after treatments (DAT) in a random sampling way using a 1 m^2 quadrate frame. Plants coming under each quadrant were measured for plant height with vegetative shoot (VS) and reproductive shoot (RS), respectively, while these plant samples were harvested for measurement of fresh weight and dry weight. Plant fresh weight was determined immediately after the collection of samples and then dried in oven at 105 ^oC for 15 minutes, followed by drying at 65 ^oC till constant weight to determine plant dry weight.

Statistical Analysis

SPSS statistical analysis software package (SPSS 19 Windows for, Chicago, USA) and Excel 2007 were used for data analysis, while the LSD test at 0.05 probability level was used for multiple comparison.

RESULTS AND DISCUSSION

Application of the plant growth regulators at different concentrations enhanced the growth of *S. krylovii* plants after 7 and 14 days' treatments (Tables 2-6). After 7 days of treatment, application of 100 mg L^{-1} NAA substantially improved the height of vegetative shoot (19%), plant fresh weight (20%) and plant dry weight (19%) of *S. krylovii* as compared to control, but 200 mg L^{-1} NAA decreased these traits. However, height of reproductive shoot was decreased by application of 20 mg L^{-1} NAA which then increased beyond this concentration with maximum increase of 4%, obtained by application of 200 mg L^{-1} NAA, when compared with control. However, at 14 DAT, application of 20 mg L^{-1} NAA enhanced the height of vegetative shoot (10%), plant fresh weight (6%) and plant dry weight (10%), while height of reproductive shoot (1%) was increased by the 100 mg L^{-1} NAA spray, when compared with control. Nonetheless, application of 200 mg L^{-1} NAA lowered plant growth of *S. krylovii*, as compared to control (Table 2).

A significant increase in *S. krylovii* plant growth was caused by the 6-BA spray. After 7 days' treatment, there was maximum increase in height of vegetative shoot (1%), plant fresh weight (22%) and plant dry weight (30%) by application of 5 mg L^{-1} 6-BA spray, as compared to control. However, application of 6-BA at higher concentrations *i.e.* 25 and 50 mg L^{-1} caused a reduction in height of vegetative shoot and plant dry weight, while height of reproductive shoot was decreased by application of 6-BA until a concentration of 25 mg L^{-1} and increased at 50 mg L^{-1} 6-BA by 12% as compared to control. However, at 14 DAT, height of vegetative shoot (11%) and reproductive shoot (6%), and plant fresh weight (10%) and dry weight (11%) were enhanced mostly by application of 25 mg L^{-1} 6-BA, when compared to control; nonetheless, application of 5 mg L^{-1} 6-BA gave statistically similar results for plant fresh and dry weight. There was a decrease in *S. krylovii* growth by application of 50 mg L^{-1} 6-BA, when compared to control (Table 3).

The BR spray on *S. krylovii* resulted in enhanced growth and development. It was noticed that, at 7 DAT, application of 0.2 mg L^{-1} BR increased the height of vegetative shoot (20%), and the 2 mg L^{-1} BR spray increased height of reproductive shoot (8%), while maximum increase in plant fresh weight (22%) and dry weight (22%) was caused by the 0.02 mg L^{-1} BR spray, as compared to control. However, application of BR at the concentration of 0.2 mg L^{-1} BR caused reduction in growth attributes as compared to control. However, 14 DAT a decrease in height of vegetative and reproductive shoot occurred by BR application at all concentrations while plant fresh (18%) and dry weight (17%) was enhanced with maximum increase caused by 2 mg L^{-1} BR treatment, as compared to control. A decrease in plant fresh and dry weight was noticed by application of 0.2 mg L^{-1} BR, when compared to control (Table 4).

Plant growth and development of *S. krylovii* was enhanced in response to application of SNP + forchlorfenuron. After the 7 days' treatment, maximum increase in height of vegetative shoot (20%) was caused by application of 50 mg L^{-1} SNP + 2.5 mg L^{-1} forchlorfenuron, height of

Table 2 **-** Effect of NAA on the growth of *Stipa krylovii* in Xilin Gol Grassland

Treatment	Plant height of VS (cm)		Plant height of RS (cm)		Fresh weight (g per plant)		Dry weight (g per plant)	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
CK	22.18±1.05b	19.34±0.49b	56.04±1.31ab	57.34±1.03a	7.93±0.57b	7.24±0.32a	4.80±0.36b	4.75±0.22ab
NAA 20 mg L^{-1}	23.45±1.94ab	21.19±0.94a	52.71±2.97b	53.48±2.54b	9.40±1.01a	7.70±1.08a	5.58±0.60a	5.24±0.70a
NAA 100 mg L^{-1}	26.49±2.13a	19.92±1.12ab	56.77±2.37ab	58.07±3.11a	9.52±1.28a	6.39±0.61b	5.73±0.76a	4.18±0.41b
NAA 200 mg L^{-1}	22.08±1.30b	20.90±1.10a	58.28±2.14a	55.09±4.52ab	7.16±0.90b	6.77±0.74ab	4.65±0.52b	4.58±0.46a

VS - vegetative shoot, RS - reproductive shoot NAA - naphthalene acetic acid, DAT - days after treatments. The values in the Table are means of at least 5 replicates ± SE. The values followed by the same letter within the columns are not signiûcantly different according to the LSD test (P<0.05).

Table 3 **-** Effect of 6-BA on the growth of *Stipa krylovii* in Xilin Gol Grassland

Treatment	Plant height of VS (cm)		Plant height of RS (cm)		Fresh weight (g per plant)		Dry weight (g per plant)	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
CK	22.18±1.05a	19.34±0.49a	56.04±1.31ab	57.34±1.03a	7.93±0.57b	7.24±0.32a	4.80±0.36b	4.75±0.22b
6-BA 5 mg L^{-1}	22.4±1.35a	19.29±0.93a	51.96±1.65b	54.07±3.10ab	9.68±1.93a	7.94±0.87a	6.25±1.33a	5.16±0.58a
6-BA 25 mg L^{-1}	14.12±3.13b	21.54±1.43a	55.12±2.88ab	61.00±2.70a	8.15±0.83ab	7.94±0.99a	4.93±0.53b	5.25±0.64a
6-BA 50 mg L^{-1}	21.76±0.70a	19.07±1.52a	62.67±1.21a	52.91±2.24b	8.07±1.53a	6.77±0.70b	4.90±0.86b	4.26±0.43b

VS - vegetative shoot, RS - reproductive shoot. 6-BA - 6-benzylaminopurine, DAT - days after treatments. The values in the Table are means of at least 5 replicates ± SE. The values followed by the same letter within the columns are not signiûcantly different according to the LSD test (P<0.05).

Table 4 **-** Effect of BR on the growth of *Stipa krylovii* in Xilin Gol Grassland

Treatment	Plant height of VS (cm)		Plant height of RS (cm)		Fresh weight (g per plant)		Dry weight (g per plant)	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
CK	22.18±1.05b	19.34±0.49a	56.04±1.31ab	57.34±1.03a	7.93±0.57ab	7.24±0.32b	4.80±0.36ab	4.75±0.22b
BR 0.02 mg L^{-1}	19.84±3.41b	19.00±1.65a	52.91±3.00b	51.57±4.34b	9.64±1.34a	7.69±1.25ab	5.86±0.83a	5.06±0.84ab
BR 0.2 mg L^{-1}	26.63±4.07a	18.73±1.10a	52.99±2.92b	55.64±4.92a	7.52±0.79ab	7.17±0.80b	4.43±0.48ab	4.81±0.58b
BR 2 mg L^{-1}	21.73±1.50b	16.72±2.74b	60.51±2.02a	52.69±2.07ab	6.90±0.74b	8.57±1.36a	4.12±0.44b	5.55±0.87a

VS - vegetative shoot, RS - reproductive shoot. BR - brassinosteroid, DAT - days after treatments. The values in the Table are means of at least 5 replicates ± SE. The values followed by the same letter within the columns are not signiûcantly different according to the LSD test (P<0.05).

reproductive shoot (8%) was enhanced by 100 mg L^{-1} SNP + 5 mg L^{-1} forchlorfenuron, while plant fresh weight (8%) and dry weight (22%) were increased by 10 mg L^{-1} SNP + 0.5 mg L^{-1} forchlorfenuron as compared to control. However, at 14 DAT, height of vegetative shoot (9%), and plant fresh weight (32%) and dry weight (41%) were enhanced by 50 mg L^{-1} SNP + 2.5 mg L^{-1} forchlorfenuron application, while height of reproductive shoot (7%) was increased by application of 100 mg L^{-1} SNP + 5 mg L^{-1} forchlorfenuron, which was decreased firstly by application of 10 mg L^{-1} SNP + 0.5 mg L^{-1} forchlorfenuron, as compared to control (Table 5).

Gibberellic acid spray enhanced *S. krylovii* growth. After 7 days' treatment, application of 50 mg L^{-1} GA_3 caused maximum increase in height of vegetative shoot (6%), while height of reproductive shoot (7%) was increased by application of 100 mg L^{-1} GA_3, as compared to control. However, height of vegetative shoot was decreased by application of GA_3 at concentrations of 10 and 100 mg L^{-1}, and height of reproductive shoot was decreased by application of 10 and 50 mg L^{-1} GA_3, while plant fresh weight and dry weight were decreased by application of GA_3 at all concentrations, as compared to control (Table 6).

Low and medium concentrations of NAA improved growth of *S. krylovii* as compared to the untreated control, but beyond high concentrations of NAA decreased plant growth as compared to control (Table 2). These results were similar to those of Li and Liu (2003) and Hunt et al. (2011).

Table 5 **-** Effect of SNP + forchlorfenuron on the growth of *Stipa krylovii* in Xilin Gol Grassland

Treatment	Plant height of VS (cm)		Plant height of RS (cm)		Fresh weight (g per plant)		Dry weight (g per plant)	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
CK	22.18±1.05ab	19.34±0.49a	56.04±1.31ab	57.34±1.03ab	7.93±0.57ab	7.24±0.32b	4.80±0.36ab	4.75±0.22b
SNP 10 mg L^{-1} + forchlorfenuron 0.5 mg L^{-1}	19.84±3.41b	19.83±1.48a	52.91±3.00b	55.00±3.04b	9.64±1.34a	8.39±1.08a	5.86±0.83a	5.27±0.71ab
SNP 50 mg L^{-1} + forchlorfenuron 2.5 mg L^{-1}	26.63±4.07a	21.08±1.43a	52.99±2.92b	60.40±2.64a	7.52±0.79ab	9.59±1.79a	4.43±0.48ab	6.70±1.13a
SNP 100 mg L^{-1} + forchlorfenuron 5 mg L^{-1}	21.73±1.50ab	19.54±1.43a	60.51±2.02a	61.40±2.95a	6.90±0.74b	8.01±0.87ab	4.12±0.44b	6.10±0.83a

VS - vegetative shoot, RS - reproductive shoot. SNP - sodium nitrophenolate, DAT - days after treatments. The values in the Table are means of at least 5 replicates ± SE. The values followed by the same letter within the columns are not signiûcantly different according to the LSD test (P<0.05).

Table 6 **-** Effect of gibberellin on the growth of *Stipa krylovii* in Xilin Gol Grassland

Treatment	Plant height of VS (cm)		Plant height of RS (cm)		Fresh weight (g per plant)		Dry weight (g per plant)	
	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT	7 DAT	14 DAT
CK	22.18±1.05a	19.34±0.49ab	56.04±1.31a	57.34±1.03a	7.93±0.57a	7.24±0.32b	4.80±0.36a	4.75±0.22b
GA_3 10 mg L^{-1}	19.75±4.17b	18.77±1.15b	46.83±5.60b	51.54±1.88b	7.49±0.98a	7.34±0.92b	4.54±0.60a	4.67±0.60b
GA_3 50 mg L^{-1}	23.49±1.17a	20.45±1.25a	52.85±2.11ab	56.29±2.37ab	7.78±0.89a	7.27±0.75b	4.66±0.54a	4.67±0.47b
GA_3 100 mg L^{-1}	20.96±1.34ab	21.79±0.76a	59.77±1.44a	58.77±2.12a	6.94±0.72a	9.45±1.37a	4.17±0.46a	6.08±0.85a

VS - vegetative shoot, RS - reproductive shoot. GA_3 - gibberellin, DAT - days after treatments. The values in the Table are means of at least 5 replicates ± SE. The values followed by the same letter within the columns are not signiûcantly different according to the LSD test (P<0.05).

NAA may have been an inhibitor of *Picea abies* stem cuttings in the experiment by OuYang et al. (2015). Exogenous NAA supplementations from 0.5 to 4 mg L^{-1} reduced height, leaf number, leaf length, specific leaf weight (SLW), total weight, stem weight, and leaf weight of *C. acuminate* compared to control (Li and Liu, 2003). The application of NAA at a concentration of 5 mg L^{-1} with ethanol was found to sustain the accelerated biomass productivity through day 10 and led to an approximately twofold increase in productivity (Hunt et al., 2011).

A significant increase in *S. krylovii* plant growth was caused by 6-BA and BR sprays. However, application of 6-BA at higher concentrations, i.e. 25 and 50 mg L^{-1}, caused a reduction in height of vegetative shoot and plant dry weight, while height of reproductive shoot was decreased by application of 6-BA to a concentration of 25 mg L^{-1} and it was increased at 50 mg L^{-1} 6-BA by 12% as compared to control (Table 3). These results confirmed the role of 6-BA as a plant growth stimulator (Tassi et al., 2008; Hossain et al., 2010). Treatment with BA promoted the release of suppressed lateral buds of western larch and increased the number of long shoots (Edson et al., 1991). Also, the exogenous application of BR ameliorates mowing stress and salt stress in *Leymus chinensis* (Liu et al., 2015; Li et al., 2015).

Plant growth and development of *S. krylovii* was enhanced in response to application of SNP + forchlorfenuron. (Table 5). These results also confirmed the role of SNP and fochlorfenuron as plant growth stimulators (Cruz-Castillo et al., 2002; Kim et al., 2006; Yu et al., 2013; Kaya et al., 2013). The application of exogenous sodium nitroprusside (SNP) effectively reversed chlorosis and alleviated growth inhibition of cucumber induced by Cd stress, while application of potassium ferrocyanide, an analog of SNP that does not release NO, did not show these effects. Based on these results, it can be concluded that the Cd stress-relieving effects of SNP on cucumber was due to NO from the former, and this mechanism might depend on higher Fe efficiency and antioxidant efficiency induced by SNP (Yu et al., 2013).

GA_3 foliar spray also enhanced plant growth attributes of *S. krylovii* (Table 6). These results are similar to those of Asahina et al. (2002). The application of GA_3 increased lentil plant height while decreasing seed weight per plant and 1000-seed weight (Giannakoula et al., 2012).

In conclusion, growth and development of *S. krylovii* was enhanced by application of all growth regulators as compared to control. However, among all growth regulators, application of 6-BA and SNP + forchlorfenuron caused maximum increase in growth and development of *S. krylovii* plants at 7 and 14 DAT, respectively, as compared to control. Thus, the exogenous application of the combination of these PGRs may be suggested for sustainable productivity of Inner Mongolia pastures under changing climate and overgrazing.

ACKNOWLEDGEMENTS

The authors are grateful to the National Key Basic Research Program of China (2014CB138806) and the Fundamental Research Funds for the Central Universities (XDJK2014C054).

REFERENCES

Asahina M. et al. Gibberellin produced in the cotyledon is required for cell division during tissue reunion in the cortex of cut cucumber and tomato hypocotyls. **Plant Physiol.** 2002;129:201-10.

Cruz-Castillo J.G. et al. Kiwifuit size and CPPU response are influenced by time of anthesis. **Sci Hortic.** 2002;95:23-30.

Edson J.L. et al. Inducing long-shoot growth for vegetative propagation of western larch. **New For.** 1991;5:51-60.

Gao H. et al. Impacts of grazing and mowing on reproductive behaviors of *Stipa grandis* and *Stipa krylovii* in a semi-arid area. **J Arid Land**. 2014;6:97-104.

Giannakoula A.E. et al. The effects of plant growth regulators on growth, yield, and phenolic profile of lentil plants. **J Food Comp Anal**. 2012;28:46-53.

Han B., Zhao M. Genetic comparisons between seed bank and *Stipa krylovii* plant populations. **Russian J Gen.** 2011;47(9):1084-90.

Han J.G. et al. Rangeland degradation and restoration management in China. **Rangeland J.** 2008;30:233-9.

Hossain M.M. et al. Seed germination and tissue culture of *Cymbidium giganteum* Wall. ex Lindl. **Sci Hortic.** 2010;123:479-87.

Hunt R.W. et al. The effect of naphthalene-acetic acid on biomass productivity and chlorophyll content of green algae, coccolithophore, diatom, and cyanobacterium cultures. **Appl Biochem Biotechnol.** 2011;164:1350-65.

Kaya C. et al. Alleviation of salt stress-induced adverse effects on maize plants by exogenous application of indoleacetic acid (IAA) and inorganic nutrients-A field trial. **Aust J Crop Sci.** 2013;7:249-54.

Kim J.G. et al. CPPU application on size and quality of hardy kiwifruit. **Sci Hortic**. 2006;10:219-22.

Li J.H.et al. Modulation of morpho-physiological traits of *Leymus chinensis* (trin.) through exogenous application of brassinolide under salt stress. **J An Plant Sci.** 2015;25:1055-62.

Li Y. et al. Interactive effects of soil temperature and moisture on soil mineralization in a *Stipa krylovii* grassland in Inner Mongolia, China. **J Arid Land**. 2014;6:571-80.

Li Z., Liu Z. Effects of benzyladenine and naphthalene acetic acid on growth and camptothecin accumulation in *Camptotheca acuminata* seedlings. **J Plant Growth Regul.** 2003:22:205-16.

Liu M.R. et al. Exogenous application of brassinolide ameliorates mowing stress in *Leymus chinensis* (Trin.). **Philip Agric Sci.** 2015;98:202-8.

Normile D. Getting at the roots of killer dust storms. **Science**, 2007;317:314-6.

Ouyang F. et al. Effects of cutting size and exogenous hormone treatment on rooting of shoot cuttings in Norway spruce [*Picea abies* (L.) Karst.]. **New For.** 2015;46:91-105.

Rademacher W. Plant growth regulators: backgrounds and uses in plant production. **J Plant Growth Regul.** 2015:34:845-72.

Rodriguez-Furlán C. et al. High throughput selection of novel plant growth regulators: Assessing the translatability of small bioactive molecules from *Arabidopsis* to crops. **Plant Sci.** 2016:245:50-60.

Santner A. et al. Plant hormones are versatile chemical regulators of plant growth. **Nature**. 2009;459:1071-8.

Silverstone A.L., Sun T. Gibberellins and the green revolution. **Trends Plant Sci.** 2000;5:1-2.

Tassi E. et al. The effects of exogenous plant growth regulators in the phytoextraction of heavy metals. **Chemosphere**. 2008;71:66-73.

Tong C. et al. Spatial pattern of steppe degradation in Xilin River Basin of Inner Mongolia. **J Nat Res.** 2002;17:571-8.

Wang R.Z., Gao Q. Climate-driven changes in shoot density and shoot biomass in *Leymus chinensis* (Poaceae) on the Northeast China Transect (NECT). **Global Ecol Biogeog.** 2003;12:249-59.

Wang Y. et al. Environmental effects on net ecosystem CO_2 exchange at half-hour and month scales over *Stipa krylovii* steppe in Northern China. **Agric For Meteorol.** 2008;148:714-22.

Wang W. et al. Mechanism of degradation succession in *Leymus chinensis* + *Stipa grandis* steppe community. **Acta Phytoecol Sinica**. 2000;24:468-72.

Xiao W.H. et al. Environmental factors controlling seed germination and seedling recruitment of *Stipa bungeana* on the Loess Plateau of northwestern China. **Ecol Res.** 2013;28:801-9.

Yu L.I. et al. Exogenous application of sodium nitroprusside alleviated Cadmium induced chlorosis, photosynthesis inhibition and oxidative stress in cucumber. **Pak J Bot.** 2013;45:813-9.

Yuan Z.Y. et al. Soil characteristics and nitrogen resorption in *Stipa krylovii* native to Northern China. **Plant Soil.** 2005;273:257-68.

Zhao N.X. et al. Genetic diversity and population differentiation of the dominant species *Stipa krylovii* in the Inner Mongolia Steppe. **Biochem Genet.** 2006;44:513-26.

Zhou G.S., Wang Y.H. Conversion of terrestrial ecosystems and carbon cycling. **Acta Phytoecol Sinica**. 2002;26:250-4.