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ROOT LENGTH TO WEIGHT RATIO AND WATER USE EFFICIENCY OF PERENNIAL RYEGRASS IN DIFFERENT WATER AND NITROGEN SUPPLIES

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Nitrogen, major mineral nutrient for plant growth, often limits the vegetative development and quality of ryegrass *Lolium perenne* (L). Nitrogen uptake is usually subjected to seasonal moisture availability. The objective of the study was to know response of plant root length to weight ratio (LWR) and water use efficiency (WUE) during early growth, when subjected to varying levels of moisture and N supply. Plants were subjected to low to high water and N levels. Nitrogen was applied @ 9 and 18 g m^{-2} (N_1 and N_2) along with 1.5 g P and 4.8 g K m^{-2}. Pots were irrigated uniformly from sowing till 35^{th} day after sowing (440 growing degree days GDD). Thereafter, water supply was restricted to 50 ml day^{-1} in half of the pots once a week (W_1) while the other half received 50 ml pot^{-1} on daily basis (W_2). Destructive samplings were done periodically at weekly interval from 530 growing degree days (GDD) onwards. Leaf weight ratio (LWR) showed a reduction with plants growth until 700 GDD and thereafter, either remained constant or increased slightly after 800 GDD. The decrease in LWR was observed almost at a constant rate for the treatments W_1 and W_2. Effect of the N treatments on LWR was not prominent ($P<0.05$) as observed for the water treatments ($P<0.01$). W_1 showed a greater ($P<0.01$) LWR than W_2 in all samplings. A polynomial regression fit best for the LWR when plotted against GDD for all the treatment interactions. Average WUE was higher for N_2 than N_1 ($P<0.05$). Water supply levels also showed a significant ($P<0.01$) response for WUE. The WUE of drought stress plants was observed greater than well irrigated plants. A decrease ($P<0.01$) in WUE, with plant growth, was observed common for all treatment interactions. The study suggests that limiting N and water supply decreased plant LWR and WUE. Compared to well-watered treatments, drought treatments showed relatively higher LWR as well as WUE of a ryegrass plant.

Keywords: Ryegrass, Water and N levels, Length to weight ratio (LWR), Water use efficiency (WUE)

1. Introduction

Water and nutrients mainly influence plant vegetative growth. Among the nutrients, nitrogen (N) dominates over the other nutrients required for growth and development of a plant [1]. Water availability has been identified as a most important factor limiting productivity in grasses. Grass yield is the product of the entire shoots [2], which is mainly consumed as fodder. The forage quality (Proteins) is estimated from tissue %N and has a significant response to the soil N availability. Nitrogen role on plant growth is mainly vegetative development but the amount and time of N application has a close co-ordination with the amount of water available during the crop growth season [3]. Therefore, the vegetative growth and plant dry matter (DM) accumulation is highly sensitive to drought [4]. Shoot development of grass has been extensively investigated [5, 6] however, roots growth has not been fully explored yet because of its complicated sampling procedure.

Grass plant has fibrous root system that regenerates with plant age and growth. N and water applications have shown an adverse effect on root growth and development [7]. Root growth study become important if soil moisture is limited during the vegetative growth. Successful simulation of the root growth and their distribution mainly depends on accuracy of the measurements and accuracy of root dry matter convertion into root length in a given model [8]. Such conversion is only possible when root length to weight ratio (LWR) and change in length to weight ratio of the plants root with age is properly observed during the growth. In fact, deeper roots contribute relatively greater in dry matter [9]. Roots LWR is an interesting parameter to know about the soil exploitation for nutrient and water particularly

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under rain-fed conditions [10]. Under such conditions, realisation of production mainly depends on the adequate partitioning of carbon to roots for effective utilisation of soil resources i.e. water and nutrients [11]. LWR is a simple indicator of a plant growth. However, it depends heavily on crop species, plant age, soil type, and environment. Besides that, tillage also plays an important role in LWR of a crop. Measuring exact root length is more tedious than its weight, therefore, information on such studies are always insufficient. The objective of the study was to monitor the changes occurred with age and time under different water and N rates in ryegrass root LWR and WUE.

2. Materials and Methods

The experiment was carried out at Institute of Plant Production, University of Bonn, Germany. Perennial ryegrass, an early variety Liprenta, was planted in pots (25 cm height and 10 cm diameter). All pots were filled with 2.5 kg substrate of soil sand (2:1 V/V). The soil, collected from the University Research Station, had a very low N (0.072%). Quartz sand (0.4-0.8 mm particle size) was purposely mixed to achieve maximum root material. In order to get uniform canopy structure, pots were arranged on trolley surrounded with extra rows on either side to provide boarder. Pots were covered with a transparent polyethylene sheets to provide shelter from rain. 20 seeds were planted and thinned to 10 seedlings pot^{-1} at emergence. Growing degree-days (GDD) were calculated as mean temperature of the crop growth season -4^oC. P and K were once applied to all pots at sowing time @ 1.5 and 4.8 g m^{-2}, respectively using KH_2PO_4 and KCl. Nitrogen was applied @ 9 and 18 g m^{-2} in treatment N_1 and N_2, respectively. Solution of $Ca(NO_3)_2\ 4H_2O$ containing nitrogen was prepared with de-mineralised water and was applied at 20 ml pot^{-1} in 10 splits over the growth period. First split was applied 10 days after sowing (DAS) followed by subsequent applications after every sampling on 17, 27, 36, 45, 53, 62, 70, 79, and 87 DAS.

For irrigation, an automatic water supply system was set up to irrigate each pot. Each pot was irrigated through a capillary tube connected with the main supply that was further connected with pump submerged in a reservoir of de-mineralised water. The pump discharged 50 ml water per min for each pot. A uniform irrigation was given from emergence to the onset of the drought at 36 DAS (440 GDD). Thereafter, water supply restricted to 50 ml discharge per pot per week to treatments W_1 and 50 ml per pot per day to treatments W_2.

Plant dry matter was recorded at periodic sampling on weekly intervals. At each sampling, plants of the pots were thoroughly washed. Five uniform plants out of ten were selected and dissected in roots and shoots. Roots length was recorded individually for each plant by measuring total length of all the roots from root base to the maximum of a root. The plant material was dried at 60^oC to achieve a constant weight. Ratio of root length to weight was calculated for each plant and averaged for pot and replications of a treatment. Regarding estimating of the water use efficiency, 16 pots (4 treatment combinations x 4 replications) were weighed empty and thereafter, filled with 2.5 kg substrate. Moisture contents of the substrate were measured and calibrated for the actual soil weight in pots. To determine pot's field capacity, the labelled pots were kept in trays having de-mineralised water and the water allowed to diffuse gradually in pots from bottom to reach the pot surface. On third day when tops of all pots were found wet, they were removed from the water trays and kept for an hour to drained excess water drops. The wet pots were weighed to determine water-holding capacity. The daily water supply record of the 16 pots was maintained to calculate evapotranspiration (ET) through the following equation.

$$ET = W_T - (W_E + W_S + W_P) + (W_{AW}) \qquad (1)$$

where W_T is the total pot weight on sampling day, W_E is weight of empty pot before sowing, W_S is the total dry soil weight at pot filling (excluding soil moisture), W_P is the total plant dry mass harvested from a pot at a respective sampling day and W_{AW} was the amount of the total water received by a pot from sowing to the last sampling harvest. The amount of water consumed through evapo-transpiration was subtracted from the total water supply to a pot. WUE was calculated for all the treatments as per following equation as ratio of the plant dry matter and evapotranspiration obtained from the corresponding samplings during growth.

$$WUE = DM / ET \quad [g\ kg^{-1}] \qquad (2)$$

Analysis of variance was carried out using GLM procedure of the statistical analysis series (SAS). Analysis was performed collectively for all the samplings and means where found significant were compared through LSD (P<0.05).

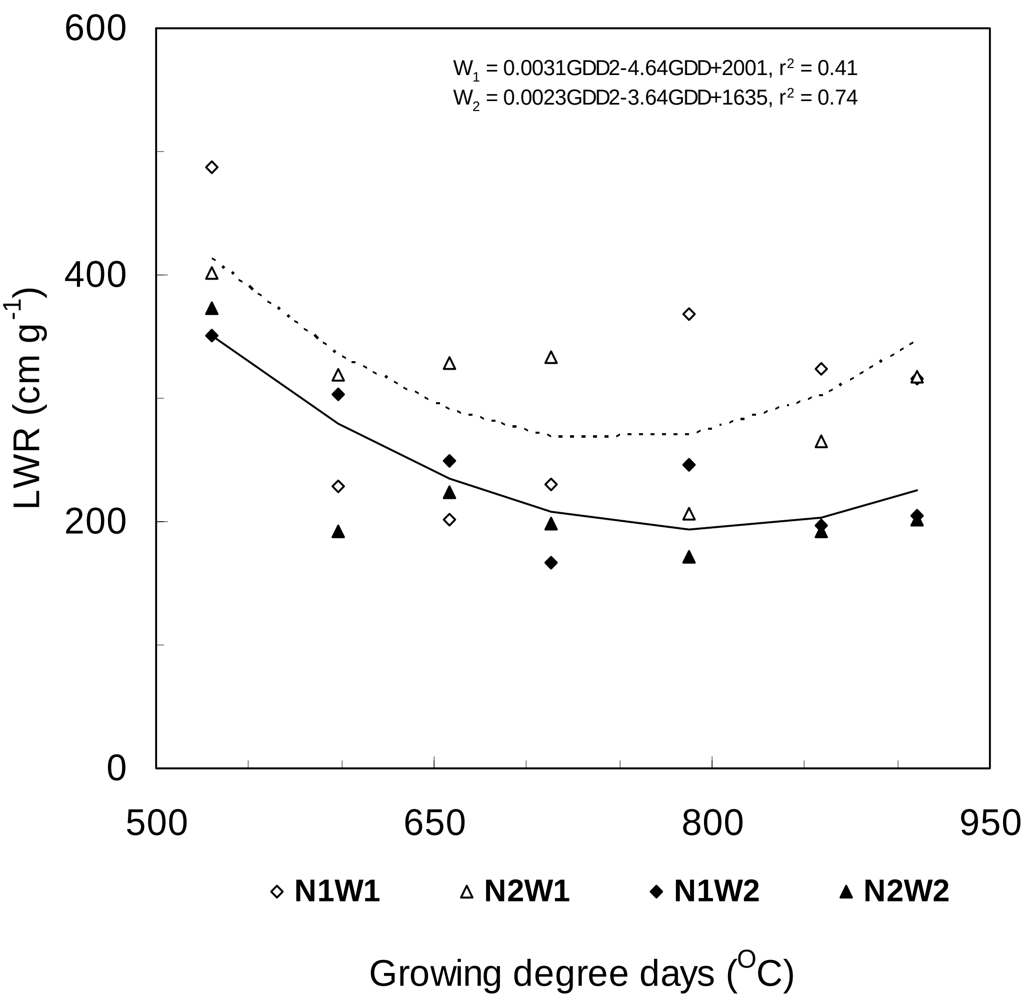

Figure 1. Relationship of the roots length to weight ratio (LWR) of perennial ryegrass planted under different water and N supplies (Low *vs.* high).

3. Results and Discussion

3.1. Roots length to weight ratio

Roots length to weight ratio (LWR) of ryegrass supplied with different water and N rates is shown in Figure 1. LWR is the ratio of dry matter and the aggregate maximum length of all roots of a plant. Low versus high N treatments did not show any significant difference in the plants LWR. Compared to shoot growth, an adverse effect of the increasing N application to the plant roots has already been observed [6]. In contrast to N application rates, differences observed in LWR were highly significant ($P<0.001$) for the water application rates to plants. The treatment W_1 compared to that of W_2 showed a higher LWR in all samplings during the period of experiment. Plants usually have to maintain a balance between roots and shoot growth. Assimilates partitioning is greatly influenced when either nutrients or water supply is disturbed during the crop vegetative growth phase [1]. LWR generally increases with time for legume crops having tap root system [12] but usually decreases for the cereals grasses like maize [13]. Tap rooted crops generally contribute for the assimilation in roots till the end of their growth while contrary to that cereal crops have a regeneration rooting system that renewed with time and age of the plants. Interactive effect of the treatments (water x N) showed a slight significant difference ($P<0.05$) in LWR. N_1 under both water supplies out yielded LWR, which might be due to adverse effect of high N on root growth. A positive response of the N deficiency on root growth of the

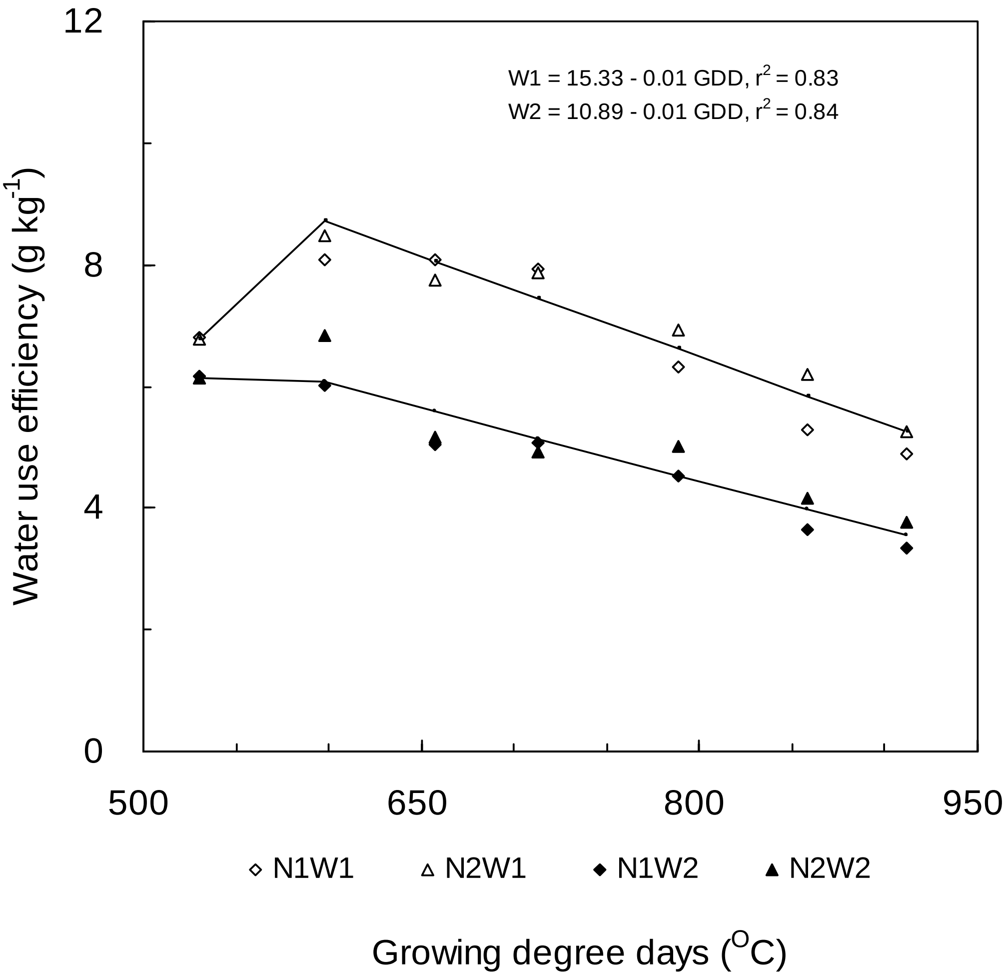

Figure 2. Water use efficiency of perennial ryegrass plants during vegetative growth planted under different water and N supplies (Low *vs.* high).

grasses has already been observed by Toth [14]. Leaf weight ratio, for all treatment combinations showed a reduction with plant age and advancement in growth. Leaf weight ratio decreases from planting till 700 GDD and thereafter, with further advancement of the plants for growth and development either levelled off or slightly increased. Increase in LWR is however, reported till 800 GDD and thereafter remained constant. Moreover, a drastic reduction in the root density was noticed for 0-10 cm compared to the 10-20 cm pots depth and likewise between 10-20 cm and 20-30 cm pot depth. This might be due to highly branched rooting of plants in the surface soil of 10 cm, as compared to the deeper layers. The decrease in LWR in early growth stage was primarily due to increase in root number of a plant that might have contributed more in dry matter rather than the increase in length of the individual roots. It should be noted that roots length was taken as aggregate of all the roots and their dry matter include weight of all roots and branches across a pot. Therefore, a reduction in LWR from start of the sampling to 700 GDD was commonly observed in all treatments. No further change in a plant LWR might be due to space limitation in pot for root and branch development or the regeneration process of cereals roots. A polynomial regression shows a best fit for LWR when plotted against GDD for the treatments W_1 and W_2.

3.2. Water use efficiency (WUE)

Water use efficiency, DM per unit water consumed, is presented in Figure 2. Water use efficiency is the ratio of water evapotranspired during growth period and plant dry matter including roots. Moisture retained in pot of the respective treatments at the time of the final harvest was excluded from total water application during growth. Mean values of the crop WUE was lower (P<0.05) for treatment N_1 than N_2 and of W_1 than W_2. However, interactive effect of treatments (Water x Nitrogen) did not differ (P<0.05) for WUE. Irrespective of water supplies, N_2 produced more dry matter than N_1 and hence reflected about 5.9% effective water utilization. Similarly, drought treatments responded 39% better WUE during the total sampling period. Higher WUE of W_1 than W_2 showed that plants utilised water in efficient way to yield dry matter when subjected to drought during growth. A decrease in WUE with advancement of growing degree-days was common for both water treatments. The higher WUE with sufficient N over the lower N rates has already been reported [15, 16, 17]. The findings have also shown similar response for the WUE under higher N supplies. High N supply to the plants enhanced its vegetative growth and hence, reflected greater WUE for N_2 compared to that of the N_1 treatments. Factors affecting WUE are the combination of evaporation and transpiration including available soil water, amount of vegetative cover, and evaporative demand of the atmosphere. Limiting water supply to the canopy enabled plants to consume water more efficiently with minimum transpiration. High WUE under stress can be attributed to higher stomatal conductance under well irrigation that favored elevated transpiration more than elevated photosynthesis [18]. However, WUE could vary between species, time of planting, stages of development, growth and re-growth status of a crop. Some other factors affecting differences in WUE are less well known than those indicated above. Species variation is particularly difficult to characterize the range in canopy morphology. Frank et al. and Frank and Karn [19, 20] measured WUE of three different grasses under field conditions and reported variations in WUE due to differences in days taken for emergence.

4. Conclusions

The findings have implication in the development of management options to improve soil moisture status and aeration of the soil e.g. drainage or excessive irrigation at the late growth stage. Besides, the plants under partial drought efficiently utilised water and hence responded higher WUE than sufficient irrigated treatments where water is not 100% effective for a crop growth and dry matter production.

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