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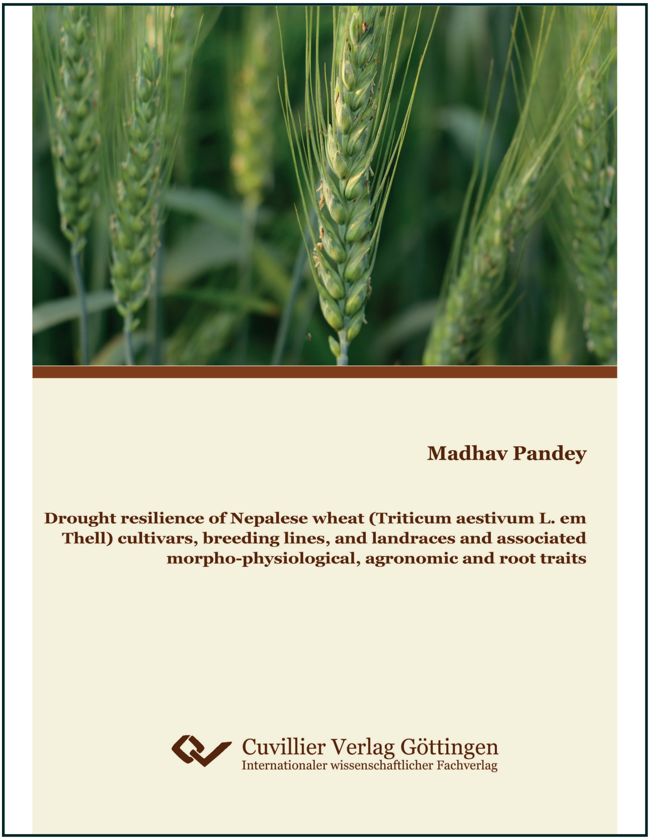
Drought resilience of Nepalese wheat (Triticum aestivum L. em Thell) cultivars, breeding lines, and landraces and associated morpho-physiological, agronomic and root traits



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Introduction

Wheat (*Triticum aestivum* L. em Thell) is one of the major cereal crops vital for global food security. The crop is important source of carbohydrates, protein, and other nutrients. The average global wheat area is estimated about 215 million ha and production of about 750 million metric tonnes, annualy. It is estimated that the global wheat demand will double by the year 2050. To meet this demand, the present yield growth of 0.9 % per year must be increased to 2.4 % per year (Ray et al. 2013). Most of this yield growth must occur in developing countries, where the wheat demand will be high due to rapid population and prosperity growth.

Wheat is an important cereal crop in Nepal, grown annually on about 760 thousand ha with a production of approximately 1.8 million tonnes. Wheat is grown in almost all the agro-ecological zones of Nepal. The largest wheat area is in Terai (~55 %), and hill and mountain agro-ecosystems represent about 38 % and 7 % of the total wheat area, respectively (Anonymous 2013). The cool and frost free winters in Teari and hills are suitable for spring wheat cultivation. In these production environments wheat is seeded in November-December and harvested in April-May. In addition to the November-May season, spring planting (May-October) is also common in the high altitude areas of the Himalayas, but the area under spring planting is negligible.

Wheat plays a crucial role in the stability of food supply in Nepal as the other two major cereals, rice and maize are grown during Monsoon season and are at high production risk due to weather hazards, such as flood or excess rain, or unsuccessful crop that may result from poor or delayed onset of Monsoon. The present wheat productivity of 3.0 tonnes/ha in Nepal is lower than that of the neighbouring countries India (3.5 t/ha) and China (5.9 t/ha). Due to the expanding settlements and development of infrastructures on agricultural lands, especially in the Terai region, it is envisaged that wheat area in Nepal will shrink in the future. Because of this, wheat productivity must be increased to meet the future demand and to improve the food security in Nepal.

Drought stress is one of the major wheat yield constraints worldwide (Trethowan and Pfeiffer 1999). It is anticipated that due to climate change impacts the incidence and severity of agricultural drought will intensify in the future and the wheat production environments around the globe will become drier and adverse causing substantial yield loss (Curtis and Halford 2014). In Nepal, about one-third of wheat is grown under rainfed condition (Anonymous 2013), and drought is one of the major wheat yield limiting factors. Moreover, of the irrigated wheat, only a smaller proportion is fully irrigated, i.e., receiving three to four irrigations and in large area only one or two irrigations are applied and therefore the crop is vulnerable to moisture stress, particularly during the post anthesis growth stages. It is assumed that due to climate change impacts greater proportion of the wheat area in Nepal will be affected by drought. A recent study (McDowell et al. 2013) showed depleted water resources in Nepal suggesting drought could be a serious wheat production constraint in the future.

Enhanced drought tolerance of wheat cultivars can compensate for yield losses due to drought stress. Drought tolerance is a highly complex trait, involving trait specific as well as whole plant level optimization of physiological, metabolic, and gene regulatory processes (Blum 1996; Seki et al. 2007; Reynolds and Tuberosa 2008). In recent years, extensive efforts have been made to improve wheat for drought stressed environment. A number of drought associated morph-physiological and agronomic traits have been identified (Richards et al. 2002; Reynolds et al. 2007; Lopes et al. 2011), and great advancements have been made in molecular and genomic tools applied in drought studies (for e.g., Semenov and Halford 2009; Fleury et al. 2010; Kumar et al. 2012). Despite the technological advancements and concerted efforts, limited success is achieved in the development of drought tolerant wheat cultivars (Blum 2014). The successes so far achieved are mainly based on empirical selection for grain yield in targeted drought environments (Trethowan et al. 2002). Selection for effective water use (WU) and water use efficiency (WUE) by using surrogate traits, such as canopy temperature (CT), carbon isotope discrimination (CID), and improvement of root system architecture, by utilizing genetic variation present in the primary and secondary gene pools are promising strategies to develop drought tolerant wheat cultivars (Reynolds et al. 2007; Trethowan and Mujeeb-Kazi 2008).

In Nepal, wheat improvement programs broadly focus on two major production domains- Terai/lower hills and Mountains/high hills and follow the conventional approach of cultivar development, i.e., selection in high production environments. The yield advantage of modern wheat cultivars is maximum in high production environment but the relative performance of these cultivars in drought is not studied in details. The drought focussed evaluation of Nepalese wheat cultivars and germplasm and identification of key drought adaptive traits will provide a basis for the development of drought resilient wheat cultivars. The following were the objectives of the present study.

1. To evaluate wheat cultivars, breeding lines, and landraces for drought tolerance in terms of grain yield resilience.
2. To study the variability of morpho-physiological traits and to identify key determinants of grain yield under drought stress.
3. To identify drought resilient genotypes.

Materials and Methods

The summary of different experiments carried out (2009-2011) is presented in Table 1. During 2009-2010 wheat season (Nov. 2009-April 2010) four field experiments were conducted. In this season, a lab experiment was also carried out to study seminal root growth angle. During 2010-2011 wheat season (Nov. 2010-April 2011), three field experiments and a pot experiment were conducted.

1. Plant Materials

Two different genotypes sets comprising of Nepalese and exotic cultivars, breeding lines, and landraces were studied. A common set of 60 geneotypes (59+check) was used for field and pot experiments (Table 2). For root study, 57 genotypes were used (Table 4), out of which 50 were common to those used for the field and pot experiments.

2. Measurement of seminal root angle

The angle of seminal root axes of 57 wheat genotypes (Table 4) were measured according to the method described by Bengough et al. (2004). Briefly, gel chamber was constructed using two clear glass plates (210 × 300 x 3 mm) and four spacer strips (clear glass, 210 x 20 x 3 mm). On each plate, two spacer strips were fixed on both edges (longer dimension) with glue, and the two other edges were sealed with a plastic tape making a 3 mm deep gel casting space. Agar solution (2 %, Sigma Type A) was prepared and sterilized in a autoclave, allowed to cool down (~65 °C) and poured onto each of the two casting plates. After 30 minutes, two plates were clamped together and kept at room temperature until further used. The gel chamber construction and casting of gel was done on a clean bench to avoid contamination. Seed samples were prepared by selecting average sized, healthy 10 seeds of each lines, washed with sterile water, and placed on wet blotting paper in a 90 mm Petri dish and kept at room temperature for 48 hr in dark to allow germination.

At the time of seed placement, two clamped gel plates were released and two healthy and vigorously germinated seeds were placed on gel of one of the two gel plates, such that radicals facing down, each seeds approximately 80 mm apart, and 50 mm from the top when the two gel plates were clamped together and kept in upright position (Figure 1). The gel chamber edges were sealed with a plastic tape to avoid desiccation, leaving about 20 mm free space on the top, towards the growth axis of the two seeds. The gel chambers were incubated in a growth cabinet at 15 °C with no light for 5 days, and then 12/12 hrs dark/light cycle for 4 days. Root growing area was covered with black paper sheets to induce darkness. Roots were scanned on 4^{th} and 9^{th} day using a flatbed digital scanner.

Table 1. Summary of different experiments carried out (2009-2011)

Experiment	Code	Location	Year	Materials[1]	Methods
1. Measurement of root architectural traits	Lab Exp.	Rampur	2009	Set A= 25 Nepalese landraces, 32 breeding lines and cultivars (n=57), out of which 50 were common to set B	Seminal root growth angle was measured using gel observation chambers according to Bengough et al. (2004)
2. Rampur 2009, Drought	R09Dt	Rampur	2009-2010	Set B= 26 Nepalese landraces, 34 breeding line and cultivars (n=60)	Genotypes were evaluated in the field under managed drought condition at Rampur using a rainout shelter
3. Rampur 2009, Rainfed	R09Rf	Rampur	2009-2010	Set B	Genotypes were evaluated in the field at Rampur under natural soil moisture condition
4. Rampur 2009, Irrigated	R09Ir	Rampur	2009-2010	Set B	Genotypes were evaluated in the field at Rampur with supplementary irrigations to maintain optimum soil moisture
5. Nawalparasi 2009	N09	Nawalparasi	2009-2010	Set B	Genotypes were evaluated in the field at Nawalparasi under natural soil moisture condition
6. Rampur 2010, Rainfed	R10Rf	Rampur	2010-2011	Set B	Genotypes were evaluated in the field at Rampur under natural soil moisture condition
8. Rampur 2010, Irrigated	R10Ir	Rampur	2010-2011	Set B	Genotypes were evaluated in the field at Rampur with supplementary irrigations to maintain optimum soil moisture
9. Nawalparasi 2010	N10	Nawalparasi	2010-2011	Set B	Genotypes were evaluated in the field at Nawalparasi under natural soil moisture condition
10. Pot Experiment	Pot Exp.	Rampur	2010-2011	Set C= Set B with # 35: NPGR 6573 replaced by drought tolerant check- Dharwar Dry	Genotypes were evaluated in pots with managed drought stress (36 % of the field capacity) and optimum moisture (72 % of the field capacity) in a shed house

[1]The Set A genotypes are given in Table 4 and Set B in Table 2.

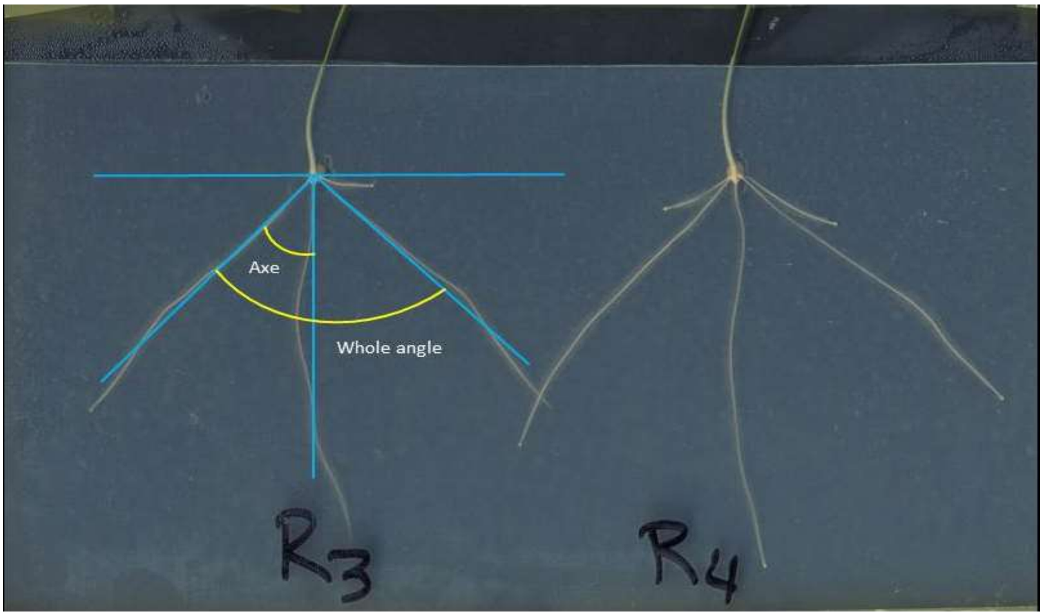

Figure 1. Measurement of seminal root growth angle- axes and whole angle (Sample: line- MILAN/S 87230/BABAX).

3. Field experiments

Field experiments were conducted at the research farm of Institute of Agriculture and Animal Science (IAAS), Rampur, Chitwan and on a farmer's field at Dobilla, Nawalparasi, 90 km west of Rampur. Rampur is located at 84.34 E and 27.65 N and Dobilla village is located at 83.77 E and 27.56 N. Both experiment sites have subtropical climate, which is highly influenced by the southwest Monsoon. In these areas, about 80 % the precipitation occurs during Monsoon season (June-September). The average annual precipitation at Rampur is 2,022 mm (Nirman et al. 2013). Specific weather data for farmer's field at Dobilla is not available but the nearest weather station located at Bairahawa (~ 35 km west) indicates that Dobilla is slightly drier than Rampur (Average annual precipitation at Bhairahawa= 1,687 mm; Tirol-Padre et al. 2007). The monthly weather data for Rampur (November 2009 to May 2011) is presented in Figure 2 and the monthly weather data for Bhairahawa (January 2009 to December 2010) is presented in Figure 3.

The soil of the research farm of IAAS, Rampur is sandy loam and that of Dobilla village area is silt-loam. In these production areas wheat growing season is from November to May. The optimum seeding time is from mid-November to mid-December. Wheat crop depends on residual soil moisture and occasional winter rainfalls that might occur in the months of January and February. To achieve potential yield and yield stability, supplementary irrigation is required.

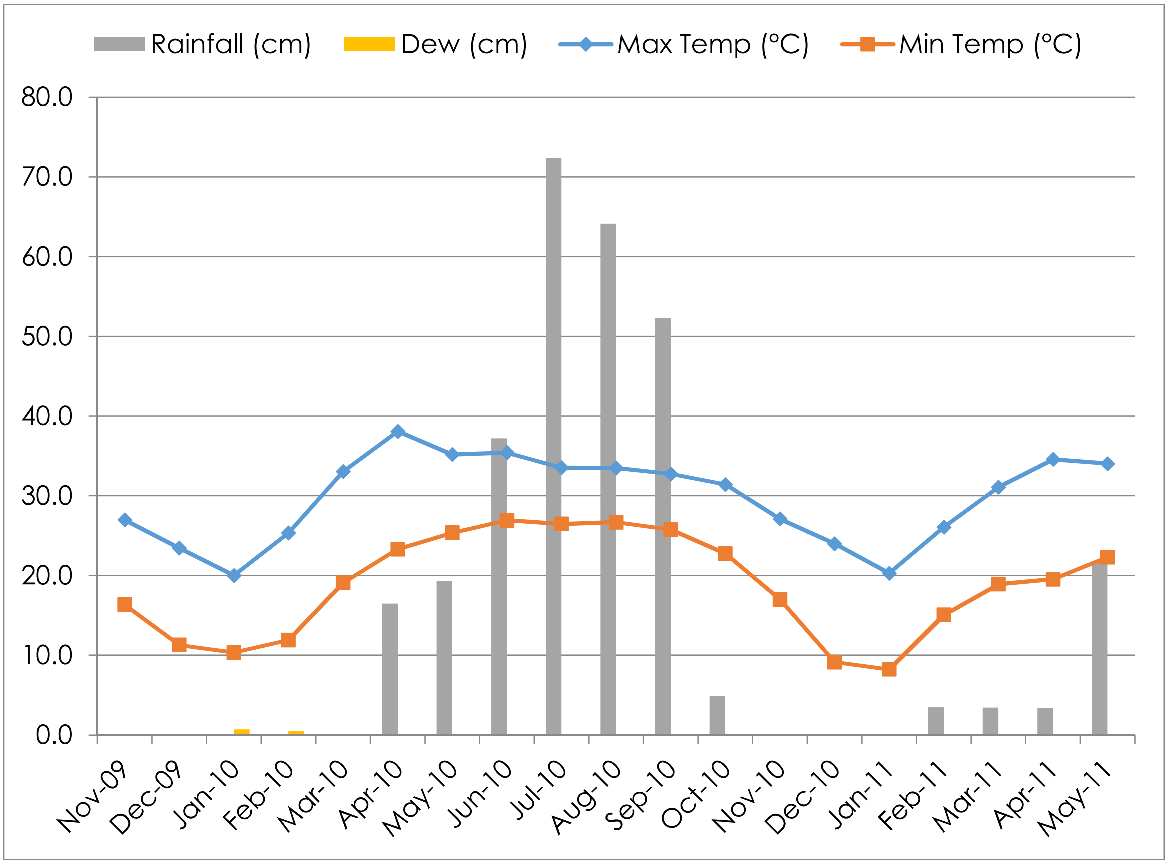

Figure 2. Monthly weather data for Rampur (Nov. 2009 to May 2011)

Sixty Nepalese wheat cultivars, breeding lines, and landraces (Table 2) were evaluated at two locations: research farm of IAAS, Rampur and on a farmer's field, Nawalparasi, for two consecutive wheat growing seasons. Three experiments were conducted at Rampur during 2009-2010 wheat season: (1) drought stressed, using a rainout shelter- Drought (R09Dt), (2) under the natural soil moisture condition- Rainfed (R09Rf), and (3) optimum moisture condition with supplementary irrigations- Irrigated (R09Ir). During 2010-2011 wheat season, two experiments: Irrigated (R10Ir) and Rainfed (R10Rf) were conducted at Rampur. The test genotypes were evaluated on a farmer's field at Dobilla village, Nawalparasi under natural soil moisture conditions during the 2009-2010 (N09) and 2010-2011 (N10) wheat seasons.