Topographic Position Influences Water Availability in Rainfed Lowland Rice at Rajshahi, Northwest Bangladesh

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The rainfed lowlands comprise level to slightly sloping bunded fields with non-continuous flooding of variable depth and duration (Zeigler and Puckridge, 1995). Rice (Oryza sativa, L.) is the major crop, with yields averaging 2.3 t ha$^{-1}$ over 36 million hectares, mainly in south and southeast Asia (IRRI, 1997). Drought is recognized as the major constraint to rice performance there (Widawsky and Oż Toole, 1990). Depending on the surrounding landscape, however, the hydrology of the rainfed lowlands differs greatly (Wade et al., 1999). Paddies in a high position lose water readily through surface runoff and seepage, while those in a low position may intercept that water. Such lateral water movement results in different depths and durations of ponded water, and different exposures to drought stress later in the growing season, at different topographic positions (Fukai et al., 2000). Soil texture (Nesbitt and Phaloeun, 1997) and soil fertility (Mazid et al., 1998) also vary across the landscape. Because soil texture and duration of ponded water are reported to vary with topographic position, various reports presume that soil water holding capacity should also vary across the landscape. No reports were located that quantified such variation in soil water characteristics and plant available water capacity of soils in different topographic positions for rainfed lowland rice. Consequently, this paper seeks to quantify variation in field-measured soil water holding capacity, and corresponding values from soil water characteristic curves, for three topographic positions in northwest Bangladesh. The implications of variation in soil water holding capacity for management and performance of rainfed lowland rice across topographic positions in a landscape are discussed.

Materials and Methods

The measurements were taken in the 1997 wet season (July-December) at Rajabari, Rajshahi, in northwest Bangladesh (latitude 24° 21’ N, longitude 88° 18’ E). Rainfall averages about 1300 mm annually, with 70% falling between June and September. Soils are dark grey clays of the Ammura series, aeric haplaquepts (UNDP/FAO/Pakistan, 1968), which soften when submerged for several days and develop deep cracks on drying. Puddled soils (0-15 cm) were mildly acidic (pH 5.8-6.3), and low in organic C (0.76-1.00%), total N (0.05-0.08%), Olsen-P (8.0-10.0mg/kg), exchangeable K (0.14-0.19 cmol/kg), and available S (10.0-11.0 mg/kg). The undulating topography had a range in elevation of about 5 m, which affected duration of ponded water and rice productivity (Mazid et al., 1998). The Dhaka-Rajshahi Highway, elevated to avoid submergence during the flood season, is the highest feature in the landscape, and was used as the reference point to determine whether samples were taken at high, medium or low topographic positions, at about 1, 3 or 5 m lower than the highway, respectively.

Undisturbed soil cores were taken from 0-10, 10-20 and 20-30 cm depth increments from each of four sampling sites in low, medium and high topographic positions, for determination of soil water characteristic data (Klute, 1986). Concurrently, soil samples were collected for particle size analysis and soil organic matter. Whenever soil water samples were taken, soil penetration resistance (Pr) was measured using a SoilTest CL-700A Pocket Penetrometer at 5, 15 and 25 cm soil depths. Resistance readings (kg cm$^{-2}$) were multiplied by 0.32 to obtain the equivalent values in megaPascals (MPa) (Bradford, 1986).

Soil water samples were initially taken after disappearance of surface water, but before the appearance of any surface cracks. This initial sample was taken after transplanting, after the soil was fully
wetted, and was intended to record the soil water content after free drainage, at field capacity (Gardner, 1986). A second sample was taken when leaves were fully and permanently rolled and the rice had extracted the available water from the soil (O'Toole and Moya, 1978). This second sample was intended to record the soil water content at permanent wilting point, the lower limit of plant available water content (Gardner, 1986). The soil samples were taken once each in association with a prolonged drying cycle in November 1997, following cessation of seasonal rainfall at the end of October. During this period, grain filling was actively proceeding in the transplanted crop of BRRI dhan32 rice.

Samples for field-determination of soil water content were collected using a steel sampling ring (5.0 cm internal diameter, 5.0 cm height), which was gently tapped into the soil. The ring was retrieved and all soil was carefully removed. Soil from the sampling ring was immediately weighed then dried at 72°C for 72 hours, because the only drying oven available at Rajabari could not attain the standard for soil drying of 110°C for 24 hours. Dry weights were determined and bulk densities (BD) and volumetric soil water contents \( \theta_v \) were calculated (Gardner, 1986), for 0-10, 10-20 and 20-30 cm soil depth increments. For each soil profile, the maximum plant-available water capacity (PAWC\(_{\text{max}}\)) was calculated (Gardner, 1986). For a

### Table 1

Clay, silt, sand (%), organic matter (%), mean volumetric soil moisture content at 0.03 and 1.5 MPa suction and plant available soil water content (PAWC=\( [\theta_{0.03\text{MPa}}-\theta_{1.5\text{MPa}}] \times 100 \)) from three soil depths in high, medium and low topographic positions (means of four sampling sites) at Rajshahi, Bangladesh in 1997. PAWC determined in the laboratory.

| Topography / Soil depth | Clay (%) | Silt (%) | Sand (%) | OM (%) | \( \theta_v \) (0.03 MPa) | \( \theta_v \) (1.5 MPa) | PAWC (mm) |
|-------------------------|---------|---------|----------|--------|----------------|----------------|----------|
| High topographic position | 0 - 10 cm | 18.2 | 39.8 | 24.0 | 2.1 | 0.38 | 0.12 | 26 |
|                         | 10 - 20 cm | 38.2 | 37.8 | 23.0 | 1.1 | 0.44 | 0.15 | 29 |
|                         | 20 - 30 cm | 47.2 | 30.8 | 22.0 | 0.6 | 0.47 | 0.20 | 27 |
| Medium topographic position | 0 - 10 cm | 40.2 | 31.8 | 28.0 | 1.5 | 0.45 | 0.13 | 32 |
|                         | 10 - 20 cm | 42.2 | 25.8 | 32.0 | 1.1 | 0.49 | 0.15 | 34 |
|                         | 20 - 30 cm | 47.2 | 25.8 | 27.0 | 0.7 | 0.49 | 0.17 | 32 |
| Low topographic position  | 0 - 10 cm | 44.2 | 28.1 | 27.7 | 1.7 | 0.45 | 0.12 | 33 |
|                         | 10 - 20 cm | 44.2 | 28.1 | 27.7 | 1.1 | 0.50 | 0.15 | 35 |
|                         | 20 - 30 cm | 52.2 | 31.8 | 28.0 | 0.9 | 0.49 | 0.16 | 33 |
| Mean                    | 43.6 | 31.1 | 26.6 | 1.2 | 0.46 | 0.15 | 31 |
| 5% LSD                  | -- | -- | -- | -- | 0.03 | 0.04 | 3.5 |

### Table 2

Mean soil penetration resistance (Pr), bulk density (BD), volumetric soil moisture content \( \theta_v \) of soils at field capacity (FC) and wilting point (WP) and plant available water content (PAWC=\( [\theta_{\text{FC}}-\theta_{\text{WP}}] \times 100 \)) at three topographic positions in Rajshahi, Bangladesh in 1997. PAWC determined in the field.

| Topography / Soil depth | \( P_r \) (MPa) | BD (g cm\(^{-3}\)) | \( \theta_v \) (cm\(^{-3}\) cm\(^{3}\)) | PAWC (mm) |
|-------------------------|----------------|----------------|----------------|----------|
|                         | FC | WP | FC | WP | FC | WP |
| High topographic position | 0-10 cm depth | 0.0 | 1.50 | 1.45 | 1.52 | 0.38 | 0.14 | 24 |
|                         | 10-20 cm depth | 0.41 | 1.60 | 1.77 | 1.70 | 0.31 | 0.17 | 14 |
|                         | 20-30 cm depth | 0.15 | 1.47 | 1.66 | 1.65 | 0.32 | 0.20 | 12 |
| Medium topographic position | 0-10 cm depth | 0.0 | 1.60 | 1.45 | 1.55 | 0.42 | 0.16 | 26 |
|                         | 10-20 cm depth | 0.72 | 1.50 | 1.75 | 1.64 | 0.31 | 0.17 | 14 |
|                         | 20-30 cm depth | 0.44 | 1.41 | 1.70 | 1.68 | 0.36 | 0.21 | 10 |
| Low topographic position  | 0-10 cm depth | 0.0 | 1.25 | 1.43 | 1.28 | 0.46 | 0.10 | 36 |
|                         | 10-20 cm depth | 0.50 | 1.60 | 1.58 | 1.62 | 0.36 | 0.13 | 23 |
|                         | 20-30 cm depth | 0.16 | 1.60 | 1.73 | 1.61 | 0.31 | 0.17 | 14 |
| Mean                    | 0.27 | 1.63 | 1.58 | 0.35 | 0.16 | 19 |
| 5% LSD                  | 0.20 | 0.73 | 0.08 | 0.04 | 0.03 | 6.1 |
depth increment of 100 mm, the total water content of
the soil at each sampling is \(100^*\theta_v\) (mm), \(\text{PAW}_c\) is
the difference in total water content between field
capacity and wilting point, accumulated over the depth
increments of the soil profile (mm). ANOVA were ob-
tained using BSTAT (McLaren, 1996).

Results and Discussion

Soil texture was generally clay, except at high
topographic position where the texture was clay loam
in the top 20 cm (Table 1). Organic matter content
was greater than 1.5% in the surface layer of all three
positions, and declined with depth to 0.6-0.9%. In the
water characteristic data (Table 1), water contents were
lower in the surface layer than in deeper soil layers. At
0.03 MPa, water contents were 0.38 cm cm\(^{-3}\) at 0-10 cm
in the topographic position, but were about 0.47
cm cm\(^{-3}\) elsewhere. At 1.5 MPa, water contents ranged
from 0.12-0.20 cm cm\(^{-3}\), and increased slightly with
depth.

For the field samples, penetration resistances were
less than 0.5 MPa at field capacity, but were about 1.5
MPa at wilting point (Table 2). Bulk densities ranged
from 1.44 to 1.73 g cm\(^{-3}\), with mild increases at depth.
Volumetric water content at field capacity was higher
at the soil surface and declined with depth in the
puddled soil. In contrast, volumetric water content
at wilting point was lower at the soil surface and
increased slightly with depth. The slightly lower water
content at 0-10 cm may indicate a small evaporative
loss at the soil surface below the standing crop with
permanent leaf rolling.

From the water characteristic data, maximum plant-
available water capacities were 81, 98 and 101 mm
for the top 30 cm of soil in high, medium and low
topographic positions (Table 1). When calculated
from field samples, however, the equivalent values
were 50, 50 and 73 mm (Table 2). Small errors for
both laboratory and field samples were introduced with
soil drying at 72°C, which would be greater at
field capacity. The discrepancy between laboratory
and field samples was mainly due to overestimation
of water contents at field capacity on the pressure
plate apparatus, suggesting the undisturbed cores did
not fully equilibrate at 0.03 MPa in the laboratory.
Consequently, the field-derived values are preferred.
The field-derived values for maximum plant-available
water capacity should be sufficient to meet evapora-
tive demand in November for periods of 17, 17 and 24
days at high, medium and low topographic positions, when
pan evaporation is about 3 mm d\(^{-1}\).

According to Saleh et al. (2000), water supply to
rainfed lowland rice in Rajshahi is adequate for 5 years
in 10, some drought is experienced for 5 years in 10,
and severe late season drought occurs for 2 years in 10.
When severe late season drought occurs, little

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