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# Mungbean response to surface drainage when grown as a pre-rice crop on waterlog-prone ricelands

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## Abstract

Large areas of the world's bunded rainfed lowland ricelands could be planted to a pre-rice crop if waterlogging damage during the early wet season is prevented. To build understanding necessary to develop effective field drainage practices for pre-rice crops, pot and field studies were undertaken on a Typic Tropaquept lowland rice soil in the Cagayan Valley, Philippines. The objective of the studies was to quantify effects of excessive moisture on mungbeans (*Vigna radiata* (L.) Wilczek) encountering variable regimes of duration and elevation of water table height in the root zone during a short-term waterlogging event. Small differences in level and duration of the root zone water table markedly affected plant performance. Yields were reduced by 40–100% when the water table level reached the soil surface for 6 days compared with the unstressed treatment, but were reduced by only 12–17% when the water level was 5 cm below the surface for the same time period. Regression analysis revealed a 4% reduction in yield per centimetre increase in water table level between 5 cm below to 5 cm above the soil surface during the vegetative stage, and a 6.5% reduction per centimetre during the reproductive stage. Field experiments evaluated two prospective surface drainage techniques that farmers could employ to elevate the crop above the zone of saturation during waterlogging events. Planting in furrows, and subsequently hilling up (HU) to create ridges was unsuccessful in improving plant performance (as the base of the plant was not elevated). Planting on 25 cm high ridges formed by a plow dramatically improved growth and yield of mungbean ($\geq 360\%$ advantage compared with the other treatments) when subjected to a range of waterlogging stress events. Standing water occurred for 5–7 days on the soil surface of HU, broadcast seeded (B), and drilled (D) treatments, but was 5–6 cm below the base of the plants in the ridge treatment during the two flooding events. The ridging method was observed to be effective for farm-scale use in cultivating pre-rice mungbeans with either animal or tractor power.

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## 1. Introduction

There are approximately 30 million ha of rainfed lowland riceland in Asia (Garrity et al., 1986). Most of this rice (*Oryza sativa* (L.)) area has a low cropping intensity. It is planted to only one crop of transplanted rice per year, with no preceding or following crops. The production of a pre-rice crop during the dry-wet transition period may increase farm income. The early rains can be used to successfully grow a short-maturing upland crop such as mungbeans (*Vigna radiata* (L.) Wilczek), as the rice crop is transplanted later in the wet season as the rains intensify and the fields flood.

The pre-rice growing period of 60–90 days is characterized by periodic excessive moisture and by intermittent water stress, during which there is a gradually lengthening photoperiod (Zandstra et al., 1982). Three major problems are associated with upland crop production early in the rainy season: (1) waterlogging due to intermittent heavy rains on soils with typically poor surface and internal drainage, (2) drought stress due to erratic rainfall, and (3) pests and diseases, particularly for legume crops. Waterlogging is the predominant yield limiting problem in many, if not most, situations.

Intermittent shallow surface flooding occurs because the fields cannot be externally drained, due to an insufficient paddy-to-paddy slope gradient. Vertical infiltration is slow due to the typically fine-textured soils of bunded ricelands. The waterlogging damage to pre-rice upland crops becomes progressively more severe the longer the inundation (Herrera and Zandstra, 1979).

During periods when soil is saturated severe oxygen deficiency can develop rapidly in the roots, causing root death and subsequently death of the entire plant (Geisler, 1965; Herrera and Zandstra, 1979). In sensitive plants, symptoms and injury can become evident in both roots and shoots. Absence of soil oxygen initiates a sequence of chemical and biochemical reduction reactions, producing components that may be injurious to root metabolism (Jackson and Drew, 1984). Lateral root extension and number are reduced by low concentrations of oxygen (Geisler, 1965). Plants which can survive an anoxic stress decrease their root growth rate (Jackson and Campbell, 1979).

Field drainage may be a suitable solution if the soil surface is manipulated to maintain adequate aeration in the upper root zone of the growing crop in the event of sustained moisture. The field configuration depends upon an understanding of the critical aeration level in the crop root zone. The determination of critical aeration levels for several crops has been reported by Grable (1966), Letey et al. (1962), Tackett and Pearson (1964). Drainage often implies the installation of sub-surface pipe systems in Western agriculture. However, ridge and furrow systems may be effective, and were among the first drainage systems used (Trafford, 1970).

Two-thirds of the ricelands in the Cagayan Valley, Philippines is rainfed, and most of this is located on alluvial river terraces. A single rice crop is transplanted in August and the land lies fallow due to waterlogging during the long dry-wet transition period beginning in April. Mungbean production is practiced as a low investment, high risk enterprise on only the better drained landscape positions of the alluvial river terraces, with total crop losses observed more than 50% of the time (International Rice Research Institute, 1984).

In the rainfed lowland ricelands of southern Thailand, the production of pre-rice crops is not attractive to farmers due to waterlogging problems (Crozat, 1985). Few farmers ( < 3%) grow mungbean during the early rainy season. In 3 out of 4 years, crops are seriously damaged by waterlogging (Crozat, 1985). During the 1984 dry-wet transition period, considered representative of the expected rainfall distribution (80% probability) for the area, 17 of 22 fields yielded less than 0.1 t $ha^{-1}$. In 24% of the cases, no harvest was possible due to complete plant mortality.

It was hypothesized that a practical solution lies in developing field drainage practices that manipulate the soil surface configuration to keep the upper root zone of the crop above the saturated zone in the event of heavy rainfall. Controlled studies were conducted to quantify the effects of excess moisture due to variable periods of surface flooding and high water table levels on the growth of mungbeans. The quantitative effects of modest differences in the depth and duration of the free water level on mungbean were of particular interest. Such differences could be generated by agronomic manipulation of the soil surface configuration, or by seeding methods (surface broadcast or sub-surface drilling) which create differences in the relative elevation of seed placement in relation to the soil surface.

Subsequently, field experiments were conducted to determine the potential effects of alternative ridging or bed formation techniques on the displacement of surface water in poorly drained, bunded fields, and on the resulting performance of mungbeans. This work was the initial phase of a project to model the soil water dynamics of the dry-wet transition period to predict the degree of surface configuration required to stabilize mungbean production across different micro environments.

## 2. Materials and methods

Two sets of experiments were conducted in an alluvial terrace landform of the Cagayan river basin at Solana, Cagayan, Philippines in 1986 and 1987. The general characteristics of the site, including landforms, and flooding regime were described in Baquiran et al. (1983).

### 2.1. Water table dynamics studies

This portion of the work consisted of two experiments that were planted from February to April and from July to September in 1986 to evaluate the response of mungbean to excessive soil moisture when the free water level varied in depth and duration. Steel cans of 24 cm length × 24 cm width × 36 cm depth were used to create the water table treatments. The cans were filled with surface soil from the 0–20 cm layer of the research site and placed on benches in the field. The soil was a Typic Tropaquept (Tagulod soil series) with a clay content of 54%, silt of 43%, and sand 3%; soil pH of 6.2 (1:1 v/v in water); and an organic carbon content of 16 kg $Mg^{-1}$. Soil was packed into the cans to a bulk density similar to that of farmers' fields at the research site (Table 1).

Mungbean seeds were placed 2.5 cm below the soil surface, or alternatively broadcast on the soil surface. Fifteen seeds ('CES ID21') were planted in each can and thinned to

Table 1
Soil bulk density (Mg $m^{-3}$) at harvest in the ridge and drill treatments in the 2 locations of the field experiment, and in the cans used for the pot experiment

| Soil depth (m) | Ridge | | | Drill | | | Pot expt. |
|---|---|---|---|---|---|---|---|
| | Stratum 1 | Stratum 2 | Mean | Stratum 1 | Stratum 2 | Mean | |
| 0–0.05 | 1.02 | 1.16 | 1.09 | 1.18 | 1.22 | 1.20 | 1.23 |
| 0.05–0.10 | 1.03 | 1.25 | 1.14 | 1.28 | 1.22 | 1.25 | 1.18 |
| 0.10–0.15 | 1.23 | 1.29 | 1.26 | 1.35 | 1.27 | 1.31 | 1.18 |
| Mean | 1.09 | 1.23 | 1.16 | 1.27 | 1.23 | 1.25 | 1.20 |

five plants per can at the seedling stage. Plants were irrigated as necessary to prevent water stress during the growth period before and after waterlogging treatments were applied. Plants were protected against insects and diseases. They were not fertilized, as is the normal practice on these soils, due to a high inherent P and K fertility and high cation exchange capacity.

Plants were subjected to waterlogging treatments of variable duration at different crop stages: (a) at 25 days after seeding (DAS), i.e. vegetative stage; (b) flowering stage; or (c) at both 25 DAS and at flowering stage. A series of seven water table treatments were applied at each of the two crop stages (see Table 2 for a description of the treatment, and Fig. 1 for a graphic representation of the water table depth pattern in each treatment). Treatments included manipulation of the free water level in relation to the soil surface, and the duration that the free water level was present in the root zone of the plants, as described in Table 2 and shown in Fig. 1. Treatments simulated the realistic progression of the free water level in or above the soil during temporary waterlogging events. They varied from a freely drained control which was unstressed (FD), to a treatment which was submerged for 5 days (F5; Table 2).

Treatments were composed of combinations of crop growth stage and water level regime in a randomized complete block design. Not all combinations were tested in each experiment. Treatments W7 and F2 were composed of both subsurface and broadcast seeding. Water table depths were manipulated by drainage holes drilled in the side of the cans. Rubber stoppers were inserted into the holes to control the soil water level at the designated depths for the duration of the waterlogging period, with a gradual or rapid drop in free water level imposed according to treatment (Fig. 1).

### 2.2. *Field surface drainage studies*

Two field trials of alternative surface drainage methods were conducted. One was located in a lower elevation toposequence position on the alluvial terrace in an extensive rainfed rice producing area in the Cagayan Valley (identified as Stratum 2). The other trial was conducted at a slightly more elevated landscape position (Stratum 1). The Stratum 2 experiment was conducted from July to September. The Stratum 1 experiment was conducted from August to October, 1987. They were deliberately planted later than the normal seeding time for mungbean in the pre-rice season in order to insure a relatively severe waterlogging challenge with natural rainfall. The treatments were as follows:

Table 2
Effect of temporary waterlogging or flooding at different crop stages on mungbean grain yield and total dry matter yield at two planting dates. Pot Experiment, Solana, Cagayan, Philippines, 1986

| Water table depth and duration | Seeding method | Grain yield (g per plant) | | | | | | Total dry matter yield (g per plant) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 25 DAS[a] | | Flowering | | 25 DAS + flowering | | 25 DAS | | Flowering | | 25 DAS + flowering | |
| | | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 |
| 1. Freely drained control (FD) | Subsurf[b] | 6.3 | 3.7 | 6.3 | 3.7 | 6.3 | 3.7 | 11.8 | 11.1 | 11.8 | 11.1 | 11.8 | 11.1 |
| 2. −5.0 cm for 7 days (W5) | Subsurf | –[c] | 3.0 | – | 3.4 | – | – | – | 10.7 | – | 10.5 | – | – |
| 3. (a) −2.5 cm for 7 days (W7) | Subsurf | 3.6 | 2.6 | 3.6 | 3.1 | – | – | 6.8 | 7.5 | 7.9 | 8.7 | – | – |
| (b) −2.5 cm for 7 days | Broadcast | – | 2.8 | – | 3.6 | – | – | – | 11.4 | – | 13.0 | – | – |
| 4. −2.5 cm for 10 days (W10) | Subsurf | 3.8 | – | 2.8 | – | – | – | 6.4 | – | 5.6 | – | – | – |
| 5. Saturated for 7 days (S7) | Subsurf | 3.4 | 2.2 | 2.0 | 2.8 | 2.0 | 1.5 | 6.6 | 7.8 | 5.3 | 8.2 | 4.4 | 4.6 |
| 6. (a) Flooded for 2 days (F2) | Subsurf | 4.2 | 1.8 | 1.3 | 2.3 | 2.3 | 1.0 | 7.1 | 6.4 | 4.0 | 9.4 | 4.5 | 3.7 |
| (b) Flooded for 2 days (F2) | Broadcast | – | 2.2 | – | 2.5 | – | – | – | 8.7 | – | 11.0 | – | – |
| 7. Flooded for 5 days (F5) | Subsurf | 3.4 | 1.4 | 0.0 | 2.0 | – | – | 6.9 | 5.8 | 2.6 | 5.2 | – | – |
| LSD (0.05) | | 1.0 | 0.8 | 1.0 | 0.8 | 1.0 | 0.8 | 1.6 | 1.2 | 1.6 | 1.2 | 1.6 | 1.2 |
| LSD (0.1) | | 1.2 | 1.1 | 1.2 | 1.1 | 1.2 | 1.1 | 1.9 | 1.6 | 1.9 | 1.6 | 1.9 | 1.6 |

[a] DAS, days after planting.

[b] Subsurface placement.

[c] Indicates the treatment was not included in this experiment. Treatments varied between experiments.

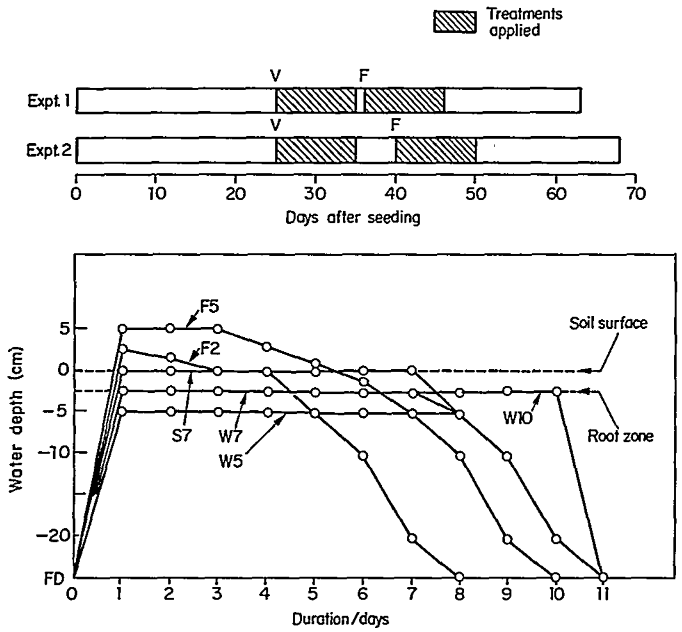


Fig. 1. The timing, duration, and water-table level of the temporary waterlogging treatments applied in the Pot Experiment. Treatment designations are discussed in Table 2. Note that the designated letter is the type of water table effect (F = flooded; S = at soil surface, i.e. saturated; W = waterlogged soil with water table below the soil surface) and the number indicates the number of days the water table remained at the designated level.

1. Ridging. Beds were constructed by a plow with water buffalo draft power, and finished by hand hoe before planting (Fig. 2). Seeds were drilled in 2 rows on top of each ridge at a distance of 30 cm between rows. Plants were thinned to 20–25 plants $m^{-1}$ at the seedling stage. Twenty-five DAS, the ridges were hilled-up to deepen the drainage canals between the beds.
2. Hilling up. Seeds were placed in 5 cm deep furrows made by carabao-driven plow. The row spacing was the same as for the ridging treatment (Fig. 3). At the seedling stage, plants were thinned to 20–25 plants $m^{-1}$. Hilling-up was carried out at 25 DAS when plants were tall enough to withstand damage during the cultivation operation. The plow created wide shallow furrows for rainwater storage.
3. Drill. This treatment was a current recommended practice for pre-rice mungbean establishment. Seeding was at 25 kg $ha^{-1}$ placed in 40 cm rows at approximately 57–59 plants $m^{-2}$ or 23 plants $m^{-1}$. Seeds were placed in 5 cm deep furrows made by carabao-drawn plow.
4. Broadcast. This treatment was the dominant farmers' practice at the research site. Seeds were broadcast uniformly after one plowing and harrowing at the rate of 25 kg $ha^{-1}$.

After planting, seed were covered with soil by harrowing with an animal-drawn spike-tooth harrow, or covered by hand in the case of planting on the ridges. Operations involved in constructing the ridges with animal power are shown in Fig. 2. The cross-sectional surface configuration due to the treatments is shown in Fig. 3. Bunds were constructed between all

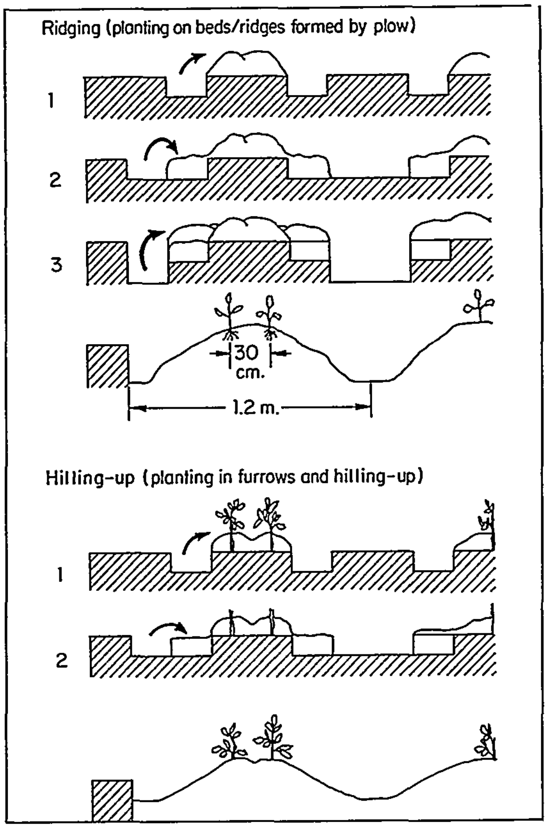
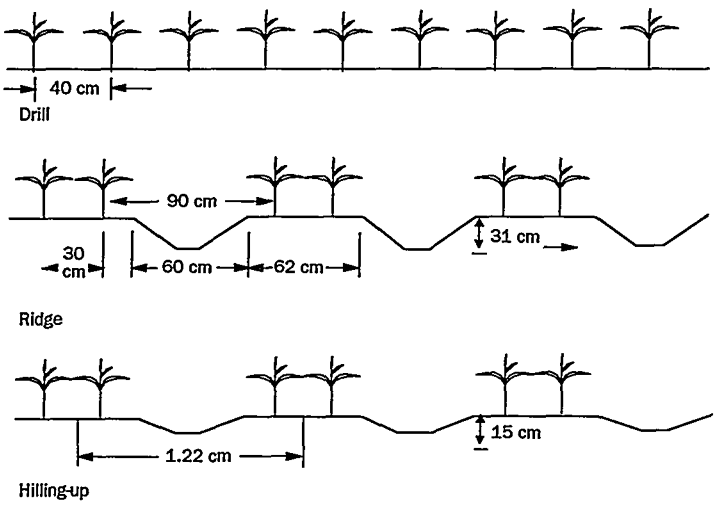


Fig. 2. Steps involved in ridging or bed formation.

plots to prevent water movement between treatments. Mercury tensiometers recorded the soil moisture tension in the ridge and drill treatments at a depth of 10 cm. Data for the ridge treatment are the average for tensiometers placed in three locations: on top of the ridge, at the middle of the side slope, and in the furrow.

Experiments were laid out in a randomized complete block design with four replications. During the waterlogging events, water depth on the soil surface was measured daily in all plots until free water was no longer present. A visual scoring of waterlogging damage (Table 4) compared the treatments in terms of wilting and yellowing of leaves. The length of the main root was measured and the total root dry weight were determined by excavation sampling after the waterlogging events.

Data for grain yield, dry-matter, plant height, and yield components were obtained by sampling areas in the center of the plots. Harvest area was 2.4m × 8 m corresponding to the area of 2 ridges × 8 m. Grain yields at maturity are reported at 120 g kg$^{-1}$ moisture content. Statistical analyses employed the Statistical Analysis System (SAS).



| Method of planting | Root zone elevational difference from ridge (cm) | | |
|---|---|---|---|
| | Stratum 2 | Stratum 1 | Mean |
| Hilling-up | 9.8 | 10.9 | 10.4 |
| Broadcast | 10.3 | 11.1 | 10.7 |
| Drill | 10.8 | 11.0 | 10.9 |
| LSD | ns | ns | |
| cv (%) | 11.9 | 4.3 | |

ns-not significant

Fig. 3. Cross-section of Ridge and Hilling-up, and mungbean root zone elevational difference from Ridge. Solana, 1987.

## 3. Results and discussion

### 3.1. Water table dynamics studies

### 3.1.1. Grain yield

Plants in Experiment 1 tolerated excessive soil moisture at the vegetative stage better than at the flowering stage (Table 2). Yield per plant was reduced 42% when waterlogging occurred at 25 DAS (average of treatments 2–7). Variation in grain yield, when compared among the different depths of water table, was not significant. Damage caused by temporary waterlogging during the flowering stage was most severe as the free water level rose from 2.5 cm below the soil surface ( $-2.5$ cm) to 5 cm standing water ( $+5$ cm) (Table 2). Flooding for 5 days at flowering (Treatment 7) resulted in total crop failure. Yield from plants flooded twice (i.e. at both 25 DAS + flowering stage) was similar to yields from a single flooding at flowering stage only.

In Experiment 2, which was conducted during the wet season, yields from the unstressed treatment (freely drained) were lower than from the same treatment in the previous dry season experiment (Table 2) due to less favorable mungbean growth conditions (less solar radiation, higher relative humidity). Among treatments waterlogged at the vegetative stage, the treatment with a water table depth 5 cm below the soil surface for 7 days had slightly reduced yields (differences were not significant). Plants flooded for 5 days (Treatment 7) had grain yields reduced 62%. During the flowering stage, temporary waterlogging below the soil surface at −2.5 or −5.0 cm was much less damaging compared to treatments in which the soil was saturated at or above the soil surface. Flooding during both growth stages further decreased yield beyond the reductions observed in either growth stage alone (Table 2).

### 3.1.2. Plant height

Flooding at 25 DAS resulted in stunted crop growth in Experiment 1. Plant height decreased significantly by 40% when plants experienced surface flooding for 5 days (F5). Plants waterlogged at 2.5 cm below the soil surface had the least height reduction compared with the freely drained control. Height reduction was less when temporary waterlogging occurred at the flowering stage, as may be expected as vegetative growth was nearly completed by this time. In Experiment 2, treatments with standing water above the soil surface produced the shortest plants in both crop stages.

### 3.1.3. Total dry matter yield

Temporary waterlogging at both plant stages significantly decreased total dry matter yield in Experiment 1 (Table 2). Reduction of plant biomass when flooding occurred during the vegetative stage varied from 40 to 45% among treatments. At the flowering stage, a water table depth of 2.5 cm below the soil surface for 7 days produced the highest total biomass (7.9 g per plant; 33% reduction) among the treatments subjected to different degrees of waterlogging. The lowest dry matter yields were from plants with standing water for 2–5 days (2.6–4.0 g per plant), and from plants flooded twice (4.4–4.5 g per plant).

In Experiment 2, treatments with temporary waterlogging at −5 cm and −2.5 cm (broadcast) did not significantly differ in total biomass compared to plants in the freely drained (control) treatment (Table 2). The lowest total dry matter yields were from plants flooded once for 5 days (5.2–5.8 g per plant) or twice flooded (3.7–4.6 g per plant).

Grain yield was strongly correlated with total dry matter yield in both experiments (Experiment 1, $r=0.84^{**}$, Experiment 2, $r=0.89^{**}$), indicating that harvest index among treatments was not significantly affected by degree of waterlogging stress. However, the slope of the regressions differed substantially between the experiments (0.53 for Experiment 1, 0.31 for Experiment 2).

### 3.1.4. Integral effects

Broadcast seeding onto the soil surface gave a significant advantage in total biomass, compared to placing the seeds 2.5 cm below the soil surface (Table 2). This suggests that the precise relative elevation of the seed, and consequently the elevation of the upper root zone of the developing plant, may be critical in its response to temporary soil saturation. In

Table 3
Plant vigor 2 weeks after the start of temporary waterlogging. Pot Experiment I, Solana, 1986

| Treatment | 25 DAS | Flowering stage |
|---|---|---|
| −2.5 cm for 7 days (W7) | 3.2 | 3.2 |
| −2.5 cm for 10 days (W10) | 4.2 | 4.5 |
| Saturated for 7 days (S7) | 5.0 | 5.8 |
| Flooded for 2 days (F2) | 4.8 | 7.5 |
| Flooded for 5 days (F5) | 7.0 | 9.0 |
| | 25 DAS + Flowering Stage | |
| Saturated for 7 days (S7) | 5.0 | 2.0 |
| Flooded for 2 days (F2) | 5.0 | 2.5 |
| LSD (0.05) | 1.2 | 1.2 |
| LSD (0.01) | 1.6 | 1.6 |
| CV (%) | 16.4 | 15.8 |

Vigor rating: 1, vigorous growth comparable to freely drained plants; 9, all dead.

all cases the surface-seeded (broadcast) treatment was similar to or superior to the subsurface planting treatment.

Plants showed visual signs of stress as early as 3 days after the imposition of temporary waterlogging. Leaves, particularly the oldest, began to wilt, followed by yellowing, drying, and death of the entire plant in severe cases. The visual symptoms progressively worsened for more than a week beyond the cessation of the waterlogging stress treatments before the plants began to recover from the stress. Plant vigor ratings varied significantly among treatments (Table 3). Degree of damage varied in proportion to the free water level. Surface-flooded treatments were severely affected. The ratings were quite low during the second saturation/flooding event in treatments that received it twice. This suggests a conditioning response was being observed, as induced by a prior exposure during the vegetative stage.

The adverse effects may be generally attributable to damage to the roots caused by oxygen deficiency (Geisler, 1965). Diffusion of oxygen is drastically reduced when the soil pore-space is predominantly filled with water, and root death occurs rapidly. The living main root length after harvest on plants subjected to waterlogging was generally less than half of the root length of plants grown in freely drained conditions (Fig. 4). Two days surface flooding at the flowering stage had quite drastic effects on root length, when flooding was applied for the first time at that stage. But root length was not affected so seriously if the flooding was applied twice, a possible indication of physiological conditioning.

Fig. 5 summarizes the mean effects of the water table treatments at different depths across the two experiments. Results indicate that plants were much more sensitive to minor variation in the precise level of free water in or above the root zone during a waterlogging event than to the growth stage at which the event occurred. A difference of as little as 2.5 cm between the −5.0 cm and −2.5 cm treatment had a major effect on observed yield reduction. This may be attributed to the fact that seed were placed at −2.5 cm so the water level treatment at this level would have fully saturated the soil porosity of the entire root zone. The −5.0 cm treatment would have had a narrow unsaturated layer above the free water level, enabling a portion of the root zone to avoid severe oxygen stress. The data in Fig. 5

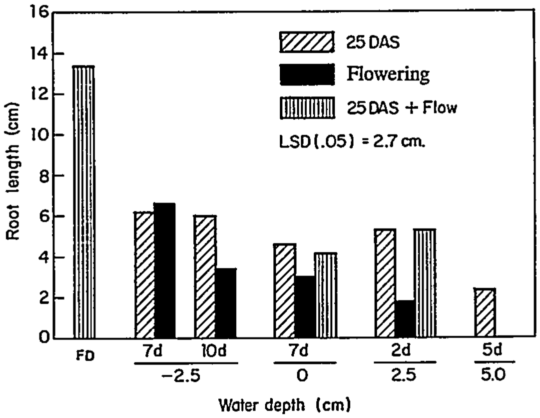


Fig. 4. Visible living main-root length at harvest. Experiment 1. Solana, 1986. FD = freely drained; d = days of flooding.

indicate a 4% drop in yield for every centimeter increase in free water level between −5.0 and +5.0 cm during the vegetative stage, and a 6.5% reduction per centimeter in the reproductive stage.

## 3.2. Field surface drainage studies

### 3.2.1. Surface configuration

In the Stratum 2 (lower elevation) field trial, the ridges were elevated an average of 15 cm before planting and 31 cm high after hilling-up at 25 DAS (Fig. 3). In the Stratum 1 (higher elevation) trial, the ridges were 25 cm high before planting, and 31 cm after hilling-up. The hilling-up operations on the ridge treatment controlled weeds growing between the beds, and deepened furrows for water storage (Fig. 3). The ridging treatment reduced soil bulk density at harvest (Table 1). The beds, i.e. the space planted with mungbean, comprised

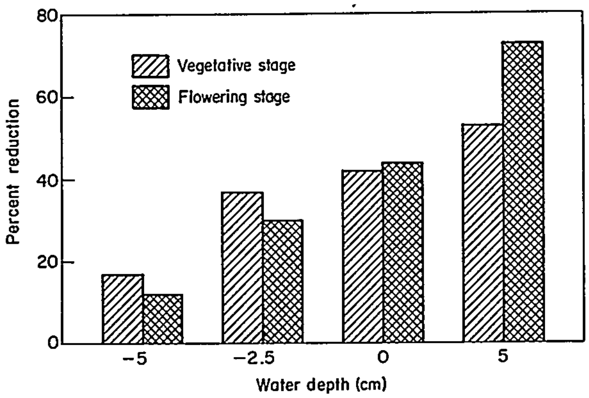


Fig. 5. Mean effect of waterlogging at different depths on yield reduction of mungbean. Pot Experiment, 1986.

51% of the total plot area. The rest of the area served as drainage furrows in both the hilling up and ridge treatments.

Planting on ridges raised the root zone 10 cm higher than when seeding was done by the other methods of establishment (Fig. 3). In the hilling-up treatment, beds were 15 cm from the bottom of the furrows to the top of the ridges.

During the rainless days 2 weeks after seeding, soil moisture tension in the middle side slope position on the ridge rose to as high as −57 kPa. Soil moisture tension in the drilled treatment rose to 78 kPa in the same period. At the late vegetative to ripening stage, a gap in rainfall caused soil moisture tension to rise to 94 kPa and 80 kPa in the ridge and drill plots, respectively. It may be hypothesized that soil moisture stress would tend to be greater for mungbeans planted on ridges during rainless periods in the pre-rice season. This is a possible disadvantage of ridging as an agronomic practice. However, the data did not suggest any significant difference between the ridge treatment and the others in soil moisture stress, indicating that this concern may not be of practical importance.

### *3.2.2. Flooding events*

Both field trials experienced two natural floodings (Fig. 6). The first flooding occurred at the vegetative stage (26 DAS) and the second at the flowering to pod formation stage (46 DAS) in the Stratum 2 trial. During the first flooding, standing water stayed above the plant root zone from 2 to 4 days on plots without surface drainage. The second flooding was of longer duration and greater depth (Fig. 6). Standing water was observed from 5 to 7 days on the soil surface of the hilling-up (HU), broadcast (B), and drill (D) treatment plots. However, in the ridge (R) treatment, excess water was efficiently drained and stored in furrows during the two flooding periods (Fig. 6). The highest water level observed in the ridge treatment was 6 cm and 5 cm below the top of the plants' root zone, during the two flooding events, respectively.

Plants in Stratum 1 trials were flooded at the seedling stage (9 DAS) and at the vegetative stage (29 DAS). Compared to the flooding in Stratum 2, water depths were shallower and of shorter duration. Standing water occurred from 2 to 4 days in the first and second floodings in the B, D, and HU treatments. Standing water in the furrows remained below the upper root zone in the R treatment.

### *3.2.3. Wilting and mortality*

The temporary waterlogging events which occurred at the two crop stages in both locations caused an immediate visual response to flooding only during the second flooding in Stratum 2, where visual reaction was first observed 7 days after the start of flooding, or when the field had already drained. Leaves of plants in the HU, D and B treatments wilted severely (Table 4). Wilting was most severe in the drill treatment. There were no wilting effects observed in the ridge treatment (Table 4).

Based on the expected plant populations, the Hilling-up treatment (35–48%) and the Drill treatment (39–41%) had the greatest mortality, compared to less than 16% for plants in the ridge treatment in Stratum 2 (Table 4). In Stratum 1, the drill treatment had the highest mortality rate (37–39%).

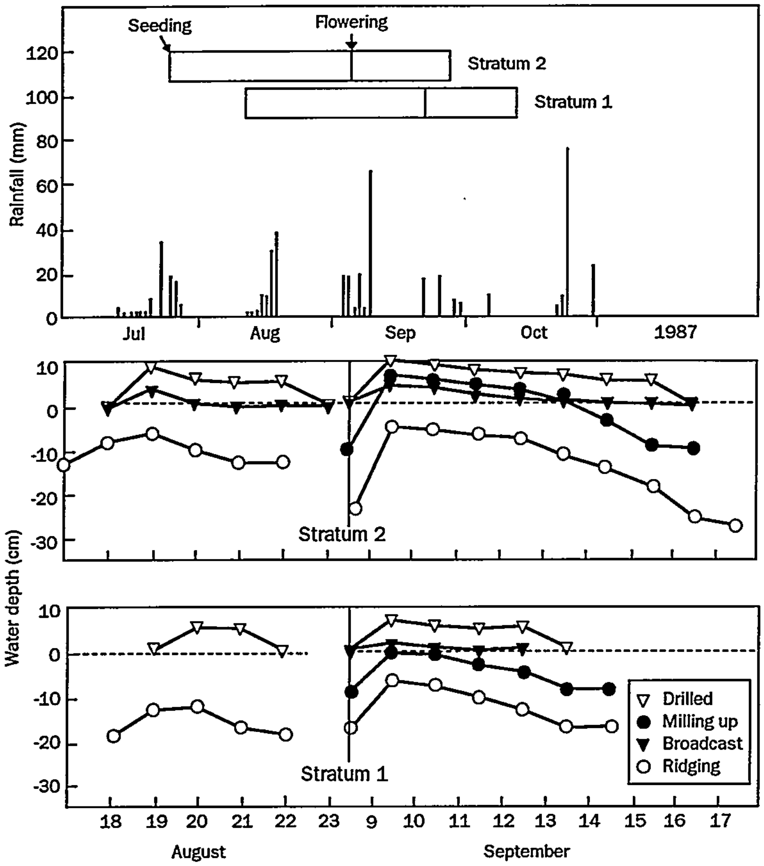


Fig. 6. Daily rainfall, flooding occurrence dates, and water depth of different methods of mungbean establishment. Solana, 1987.

### *3.2.4. Root length*

Length of the living main-root was measured at harvest to determine the extent of damage from temporary waterlogging of the root system (Table 4). Reduction in root length of plants compared to the ridge treatment was 38 to 46%, and root weight was reduced by 27–34%. These values were greater than those for the other treatments. Plants in the ridge and broadcast treatments in Stratum 1 trials had the same root length. However, root weight in the former treatment was 33% greater (4.2 g per ten plants vs. 2.6–2.8 g per ten plants; Table 4).

### *3.2.5. Total dry-matter*

In the severely flooded trial in Stratum 2, total biomass produced by plants on ridges was 2.0 to 3.5 times greater than that in any of the other treatments on a per hectare or per plant basis (Table 4). Total biomass at maturity of the ridge and broadcast treatment plants were comparable under the less severe flooding in Stratum 1. The similar total biomass in Stratum 1 was attributed to a larger number of plants per square metre in the broadcast treatment,

Table 4
The effect of temporary waterlogging and methods of establishment on yield components of mungbean. Solana, 1987

| Methods of establishment | Dry matter and yield components | | | | | Developmental and mortality | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total dry matter | | No. of pods per plant | No. of seeds per pod | Wt. of 1000 seeds (g) | Plant height (m)[a] | No. of plants[b] | | Mortality range (%) | Root length (m)[c] | Root Wt. (g per 10 plants) | Wilting score[d] 7 days |
| | t $ha^{-1}$ | g per plant | | | | | per $m^2$ | per m | | | | |
| Stratum 2 | | | | | | | | | | | | |
| Ridge | 1.52 | 4.56 | 17.0 | 8.3 | 34.9 | 0.49 | 34 | 21 | 0–16 | 0.182 | 5.5 | 1.0 |
| Hilling-up | 0.43 | 2.09 | 6.7 | 6.7 | 34.5 | 0.35 | 22 | 13 | 35–48 | 0.112 | 3.8 | 6.0 |
| Broadcast | 0.73 | 2.31 | 6.7 | 7.3 | 33.3 | 0.40 | 38 | – | 33–36 | 0.098 | 3.6 | 5.7 |
| Drill | 0.61 | 1.68 | 5.7 | 6.7 | 33.8 | 0.35 | 35 | 14 | 39–41 | 0.102 | 4.0 | 7.3 |
| LSD (0.05) | 0.29 | 1.11 | 2.6 | 1.2 | ns | 0.06 | ns | ns | | 0.033 | 1.0 | 1.5 |
| LSD (0.01) | 0.45 | 1.68 | 3.9 | ns | ns | 0.09 | ns | ns | | 0.050 | 1.4 | 2.3 |
| CV (%) | 17.90 | 20.90 | 14.3 | 8.3 | 9.3 | 0.07 | 33.9 | 19.8 | | 0.133 | 11.3 | 14.9 |
| Stratum 1 | | | | | | | | | | | | |
| Ridge | 1.80 | 5.35 | 16.7 | 7.9 | 33.8 | 0.34 | 36 | 22 | 0–12 | 0.178 | 4.2 | |
| Hilling-up | 0.69 | 2.05 | 11.5 | 7.7 | 32.5 | 0.22 | 34 | 21 | 0–16 | 0.118 | 2.6 | |
| Broadcast | 1.83 | 3.50 | 9.9 | 8.1 | 34.6 | 0.20 | 52 | – | 8–12 | 0.178 | 2.8 | |
| Drill | 1.37 | 3.84 | 10.6 | 7.8 | 33.7 | 0.20 | 36 | 15 | 37–39 | 0.113 | 2.9 | |
| LSD (0.05) | 0.11 | 1.92 | 4.4 | ns | ns | 0.40 | ns | ns | | 0.018 | 0.7 | |
| LSD (0.01) | 0.16 | 2.90 | ns | ns | ns | 0.60 | ns | ns | | 0.027 | 1.0 | |
| CV (%) | 3.8 | 26.0 | 18.0 | 12.3 | 2.7 | 0.80 | 17.8 | 17.4 | | 0.069 | 10.6 | |

[a] Measured at flowering (Stratum 2) and at vegetative stage after flood (Stratum 1), [b] at harvest, [c] living main root length, [d] 0, no wilting, 9, all plants wilting and dying. Plants scored 7 days after the start of waterlogging.

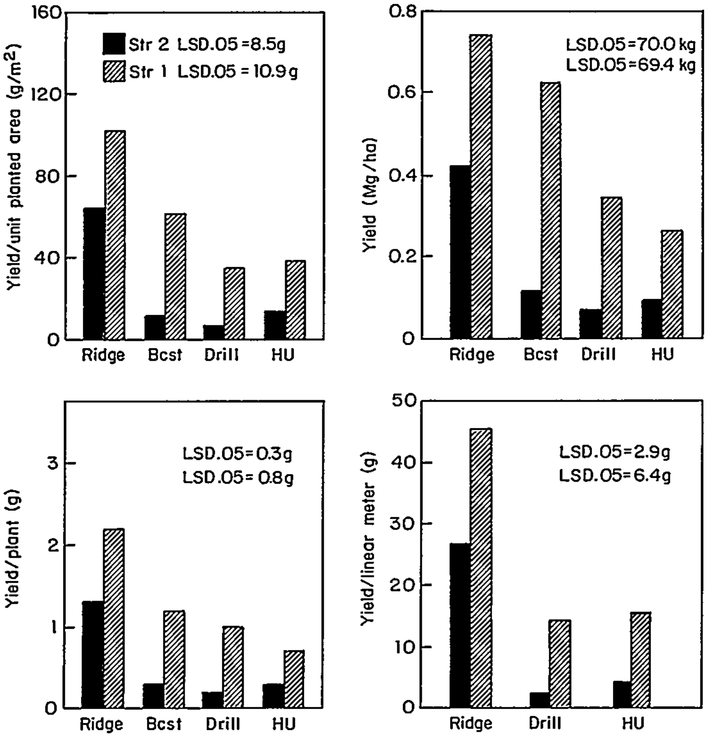
as no space was lost in this treatment due to the presence of furrows. However, mean dry weight per plant in the ridge treatment was 35% greater than in the broadcast treatment (Table 4).

### 3.2.6. *Number of pods, seeds and seed weight*

In Stratum 2, plants in the ridge treatment had 10–11 more pods per plant and 1.0–1.6 more seeds per pod than plants in treatments with other methods of establishment (Table 4). Weight per 1000 seed was comparable among treatments. In the Stratum 1 trial, the ridge treatment had 6–7 more pods per plant than the other treatments. Number of seeds per pod and seed weight were not significantly different among treatments (Table 4).

### 3.2.7. *Grain yield*

Seed yield from the ridge treatment was significantly greater than for all other methods of crop establishment (Fig. 7). The relative advantage of the ridge treatment increased as the flooding regime became more severe. Under severe flooding in Stratum 2, mungbeans planted on ridges had a 360% yield advantage (0.420 Mg $ha^{-1}$ vs. 0.115 Mg $ha^{-1}$) over the best of the three alternative treatments. Yield per unit area planted was nine times greater



Bcst = broadcast; HU = hilling up; Str = stratum

Fig. 7. Grain yield of mungbean planted on different methods of establishment. Solana, 1987.

than for the recommended practice of drill planting (Fig. 7). Yield per linear meter was 11.6 times higher, and yield per plant was 6.5 times greater than plants planted in the drill treatments.

## 4. Conclusions

Small differences in the level and duration of soil saturation in the root zone of mungbeans had marked effects on growth and grain yield. If the zone of saturation reached the soil surface or above for several days, mungbean yields were reduced from 40–100%, regardless of growth stage. If, however, the zone of saturation was restrained to 5 cm below the soil surface, the consequent yield reduction was minimal at 12–17%. These results indicate that the design of field-level surface drainage methods that elevate the crop root zone even a few centimeters may have substantial effects in raising and stabilizing pre-rice mungbean yields in waterlogging-prone rice environments.

The field experiments were set up to compare the effects of alternative crop establishment and land shaping methods on mungbean performance in the event of natural waterlogging. Methods that involved seeding the crop in shallow furrows were unsuccessful in stabilizing grain yields, even when wide surface drains were constructed during the hilling-up operation. The seed was placed below the soil surface at planting time, causing the root system to be elevationally lower than when the seed was broadcast on the soil surface. Therefore, furrow-drilled seed (where surface drains were subsequently created) was more susceptible to oxygen deficiency during any waterlogging event compared to surface broadcasting where no surface drainage was attempted.

Elevation of the seed by planting on ridges formed by the plow during land preparation, dramatically improved the growth and yield of mungbeans when subjected to waterlogging events. The ridges maintained an unsaturated zone above the water table when heavy rainfall occurred, successfully preventing a portion of the upper root zone from experiencing severe oxygen stress. This resulted in substantially higher grain and dry matter yields (≥360% increase) compared to the other treatments.

Practical surface drainage methods have potential to stabilize mungbean yields at much higher levels. Simple ridges for mungbean production may be formed using animal or tractor power. Ridge formation creates no problems to the cultivator other than additional tillage and planting effort.

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