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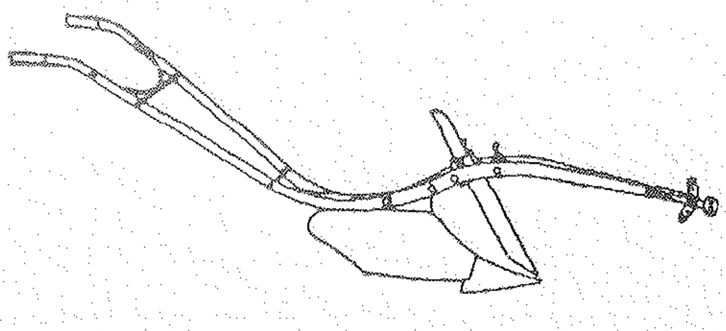
Bulletins from the Division of Soil Management



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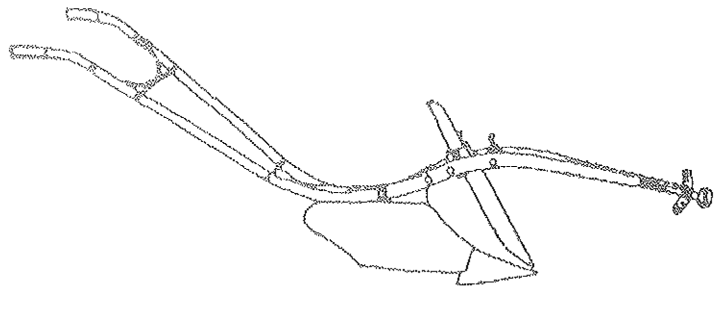

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Tillage Influences on Soil Conditions and Crop Response Under Dry Weather in the Philippines and in Sweden

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Abstract

Tillage systems under dry weather were studied to determine suitable soil conditions for seedbed preparation and crop establishment. The performance of dry season crops (soyabean and mungbean) in the Philippines as well as the establishment and yield of spring barley in Sweden were also evaluated.

The effects of delayed sowing by hand of mungbean in tilled and non-tilled seedbeds (in Experiment A) whereas effects of delayed sowing by hand or by a prototype seeder in non-tilled plots (in Experiment B) were studied in paper I to determine optimum germination and emergence. Tillage by ploughing and harrowing to 10 cm depth produced a seedbed which reduced evaporation and thermal diffusivity at 10 cm depth and below. Sowing at soil matric potential between - 0.01 and - 0.08 MPa resulted in 50-85% plant emergence when seeds were placed at 5 cm depth. A prototype seeding machine delivering seeds at only 2 cm depth on dry soil (-1.2 MPa) at 7 days after draining significantly reduced emergence.

In Sweden, in site 1, stubble tillage to 13 cm depth and conventional mouldboard ploughing to 25 cm depth in combination with 0, 1 and 3 S-tine harrowings and seeding with Nordsten, JB Special and "Ekoodlaren" were compared in terms of their effects on seedbed properties, and emergence and yield of spring barley. In site 2, direct drilling was compared with similar tillages combined with three harrowings and seed coulters as in site 1. Stubble tillage in both sites created a seedbed with greater proportion of > 5 mm aggregates compared with mouldboard ploughing. However, stubble tillage yielded better and similar amounts of grains for sites 1 and 2 respectively, with similar percent emergence as compared to conventional tillage. Direct drilling created a seedbed with > 50 % of aggregates > 5 mm, thereby reducing plant emergence but not grain yield. Harrowing beneficially influenced plant emergence more in the stubble than in conventional tillage. Nordsten seed coulter delivered more seeds at the seedbed bottom and produced greatest emergence, whereas the JB delivered more seeds at dry shallower seedbed layer resulted in lowest emergence. But, plots with less plants produced higher yield which may be partly attributed to more vigorous fewer seedlings enhancing yield compensation.

The effects of crop duration and plant population on the interception of photosynthetically active solar radiation as well as the accumulation and partitioning of soyabean and mungbean dry matter were determined. A 105-day determinate type soyabean efficiently translocated its assimilates from vegetative to reproductive growth when water stress prevailed after its maximum dry matter accumulation producing comparable yield to a 65-day determinate type mungbean. In mungbean, 0.40 million plants hectare^{-1} produced greater grain yield as compared to either 0.20 or 0.13 million plants ha^{-1}. In soyabean, greatest grain yield was obtained in the 0.2 million plants ha^{-1}, since the number of pods per plant and the mean grain mass were greater with less plants.

Preface

This thesis is based on the following papers which are referred to in the text by their corresponding Roman numerals:

I. Effects of tillage, seeding method and time of sowing on the establishment of mungbean in drying, previously puddled soil. (conducted in the Philippines)
T.P. Fyfield, P.J. Gregory, T. Woodhead and E.M. Pasuquin.
Soil & Tillage Research, 18 (1990) 333-346.

II. Effects of tillage sytems and seed coulters on seedbed properties and yield of spring barley. (conducted in Sweden)
E.M. Pasuquin, M. Stenberg and R.A. Comia (manuscript).

III. Growth of soyabean (*Glycine max*) and mungbean (*Vigna radiata*) in the post-monsoon season after upland rice. (conducted in the Philippines)
K.D. Sheperd, P.J. Gregory, T. Woodhead, R.K. Pandey and E.C. Magbujos.
Experimental Agriculture, 24 (1988) 433-441.

Contents

1. Introduction

Interaction between weather and soil factors was described more than a century ago (Lawes and Gilbert, 1880) and has been considered one of the most important determining factor in crop yield variation. Some statistical procedures have been used to analyze these variations but to a limited success, particularly if no physiological basis for the terms was used in the correlation. Another disadvantage of the statistical approach was that interactions between physical and biological processes were often ignored. It appeared that there is a need to integrate separate effects under specific conditions to understand the mechanisms behind the soil-crop interrelationship.

In Sweden, spring and early summer are dry, and crops suffer from lack of water in early summer (Tuvesson and Rodskjer, 1987). Low rainfall and high evaporation normally persists from April until August. Spring sowing must be done as early as possible to ensure the longest vegetative period, and for germination to take place before the soil surface layer dries out (Cannell, 1985). High output of the machinery is also necessary (Håkansson and von Polgár, 1979).

Similarly, a rapid drying of the soil surface is a particular feature in the tropics. When high radiation and high temperature prevails soil surface dries rapidly (Cook et al., 1990). In the Philippines, seeding legume crops, following a wetland rice is constrained by problem of establishment in poorly structured seedbed. Too early sowing will inhibit germination due to poor aeration and fungal infection while too late sowing will increase the risk of poor crop emergence due too low moisture content, a consequence of high temperature.

With similar early crop establishment condition during dry weather, this thesis is aimed to integrate various research findings from Sweden and the Philippines to pursue the following objectives:

1. To determine the effects of tillage and delayed sowing on soil conditions which affect mungbean germination, and to assess the performance of a prototype seed drill (I).
2. To study the effects of tillage systems and seed coulters on seedbed properties and on subsequent emergence and yield of barley (II).
3. To determine the growth pattern of soyabean and mungbean as affected by planting density and other environmental factors, and to determine how they relate to yield (III).

2. Review of soil conditions under dry weather

2.1 Soil structure and moisture loss by evaporation

Tillage affect the extent to which the soil is aggregated, and the properties of individual aggregates or clods, such as size, shape, internal structure, stability and spatial arrangement contribute to the resulting pore system. Thus, the quality of the seedbed formed by the tillage actions influences the rate of moisture loss. Coarse tillage leaves large cavities among the clods into which air current can penetrate resulting in increased vapor flow and greater evaporation rate (Hillel, 1968; Linden, 1982). Johnson and Buchele (1961) found that the rate of drying increased markedly as the granule size increased. In studies with columns, Holmes et al. (1960) and Gill et al. (1977) showed that aggregates < 10 mm is an optimum tilth for maximum reduction in evaporation. However, Scotter and Raats (1969) indicated that turbulent flow begins even with aggregates ranging from 3 to 5 mm.

There are two opposing factors that influence the rate of evaporation and maybe more distinct in the interface between the disturbed and the non-disturbed layer of a tilled soil. Rose (1968) attempted to establish the magnitude of vapor versus liquid water movement during evaporation under non-isothermal conditions. He suggested that the effect of warming the soil is to lower the suction and to raise the vapor pressure of soil water, hence the thermal gradient will induce flow and distillation from warmer to cooler regions. He further emphasized that when the soil surface is warmed by radiation, this effect would tend to counter the tendency to upward flow of water in response to evaporation-induced moisture gradients. This mechanism shows that evaporation rate might be lower when the surface is dried by radiation than when dried by wind (Hanks et al., 1967).

Very recent finding of Amézquita et al. (1993) showed that the first layer of the conventional tillage treatment dried to a lower water content than that of the no tillage treatment. They further reported that partition of moisture fluxes, induced by isothermal and thermal conditions showed that isothermal liquid flux was dominant in no tillage and that thermal vapor flux was very important as soil dried in conventional tillage. They found that isothermal liquid flux always being positive (upwards) and thermal vapor flux positive during the night and negative (downwards) during the day, and thermal vapor fluxes became more important with soil moisture depletion. They suspected that vapor movement under these circumstances may have played an important role in supplying water to roots both during the day (deep roots) and night (shallow roots) depending on the magnitude of fluxes. They also found vapor fluxes to be higher and to start earlier in conventional tillage than in no tillage.

2.2 Pattern and effect of soil temperature changes

Jackson (1973) and Jackson et al. (1973) reported that the surface-zone moisture content fluctuates in a manner corresponding to the diurnal fluctuation of evaporativity, that is, the soil surface dries during daytime and tends to rewet during nighttime, apparently by sorption from moister layer beneath. They found a similar pattern throughout a layer of soil several centimeters thick, and the amplitude of the diurnal fluctuation decreased with depth and time whereby the daily maxima and minima exhibited an increasing phase lag at greater depths.

Ferraris (1992) reported that shallower sowing increased the diurnal range in seed zone temperature as well as the mean temperature experienced by the seed. He further suggested that mean soil temperature was correlated with mean air temperature and soil water content such that an increase in soil water content decreases soil temperature.

Tillage systems such as plow-till, ridging and mounding or heaping tend to increase soil temperature. Several workers (Rockwood and Lal, 1974; Okigbo, 1979; Lal, 1983, 1986d; Hulugalle et al., 1985, 1987; and Opara-Nadi and Lal, 1987c) showed that plowed soils have higher maximum temperature than no-till soils. Soil temperature is also influenced both by crop residue incorporated and by the season of the year and that high ambient temperature generally resulted in higher maximum (Babalola and Opara-Nadi, 1993). Lal (1979a,b) found that plow-till and ridged seedbeds had higher maximum and lower minimum soil temperature than no-till and straw-mulched.

In the tropics, high temperature may exert a deleterious effect by reducing germination and growth of maize (Lal, 1974) when the temperature at the soil surface exceed 60 °C during the central 3-4 hours of the day, and of sorghum when the temperature at 50 mm at 14.00 hours always exceeded 40 °C (Payne and Gregory, 1988). There were indications, however, of differences between genotypes in their ability to emerge at high soil temperature.

Moreover, early effects of soil temperature on plant growth may persist throughout the crop's life. Cooper and Law (1977) found that a substantial reduction in yields of maize was a consequence of decreased soil temperature following the start of the rains. Final yield was highly correlated with the total weight of the plants five weeks after emergence, which was in turn correlated with the mean temperature experienced by the shoot meristem during these weeks.

2.3 Influence of seed coulters and presswheels

The design of soil openers determines biologically important variables such as slot shape, soil cover and residue cover (Baker, 1976) influencing plant emergence. Direct-drilling machines which placed seeds in open drill grooves with little or no coverage, as those on the dished disc, triple disc and hoe-coulters resulted in a relatively poor seedling emergence compared when seeds were sown in optimum soil coverage. Baker (1976) designed a winged 'chisel' coulter to improve seed germination and seedling establishment by retaining a soil and litter cover over the seed. This chisel coulter creates a minimal disturbance at the soil surface but produces considerable sub-surface shattering, leaving an inverted-'T' shaped groove. This has better moisture retention properties than 'V' and 'U' shaped grooves created by the triple-disc and hoe coulters. Such effects are particularly important when moisture is marginal for seedling establishment (Baker, 1980). However, if the coulter depth is not controlled on uneven ground and the coulter rides out of the soil in low patches or sows too deep, advantages are lost (Campbell, 1985). Thus there is a need for precision depth control. In Canada, McLeod et al. (1990) accounted the superior performance of two Swift Current zero-till drills to less disturbance of the stubble and soil, thereby reducing moisture loss.

In moist clay soils, triple-disc coulters, because of their shape and subsequent wedging action, tend to smear and compact the sides and base of the drill grooves. Even on soils that do not smear, compaction at the base of the triple-disc groove can reduce radicle entry (Baker, 1976). Nevertheless, seeds sown with triple-disc seeder are still likely to germinate better than if they were broadcast on the soil surface (Dowling et al., 1971).

Soil moisture loss by evaporation may be reduced by reducing air flow into the seedbed. Rollers and presswheels increased the seed-soil contact and particularly under less than optimum water potential regimes they increased germination (Choudhary and Baker, 1980; Hadas and Russo, 1974). The advantages of compaction are most evident in sandy or loamy soil, particularly when moisture for germination is limited. On the other hand, compaction appears to be of little benefit with deeper sowings (> 20 mm), or when there is ample moisture for germination (Triplett and Tesar, 1960; Norman, 1960); it may even reduce emergence by increasing mechanical impedance of clay or clay loam soils and this phenomena is observed especially in Swedish sandy soils.

3. Review of plant responses under dry weather

3.1 Response to mechanical impedance and water stress

At high soil moisture tensions there is slow seedling emergence at high energy cost, resulting in weaker seedling and slower establishment. The relationship between seedling vigour and mechanical impedance becomes more important as planting depth increases, particularly with slower emerging shoots (Brock, 1973).

When stresses occur early in seedling development they may impair potential crop yields (Chevalier and Ciha, 1986). Such stresses may include slow emergence induced by post-seeding conditions (Håkansson and von Polgár, 1984) or delayed fall emergence of wheat

(Lindstrom et al., 1976) which markedly reduce crop yield potential.

When water stress occurs late in the growing season it accelerates leaf senescence. It is almost always associated with nutrient stress such that when the high demand for nitrogen by growing grains cannot be met by uptake from the soil, nitrogen will be translocated from the green stems and leaves resulting in early senescence (Payne and Gregory, 1988).

Crop response to moisture stress depends on crop type. Guanta et al. (1993) reported that wheat yield were reduced by as high as 87 % whereas triticale by only 8 % compared with irrigated control. His further analysis showed that the most severe stress caused 60 % reduction in the number of fertile ears per unit area and by 48 % in the number of grains per ear whereas with mild stress, a reduction in weight was solely due to lower grain weight.

3.2 Response to planting density

The effect of row distance and population density on yield of particular crops has not been fully established and the present situation revealed a very variable result. Very recent findings by Sato et al. (1993) showed higher wheat grain yield in the low seeding rate (150 seeds m^{-2}). Tillers in this treatment had shoots with high nitrogen and potassium content bearing more spikes. Moreover, they found that in the high seeding density plots (300 seeds m^{-2}) grain yield was low due to low N and K in the shoots. Garg et al. (1993) reported that when plant population of pearl millet was as low as 14.5 plants m^{-2}, dry matter production and grain yield as well as water use efficiency were reduced. In this case, improved performance of individual plants under wider spacing could not compensate for losses accrued due to a decrease in plant population. Additionally, in study of spring wheat, Singh et al. (1985) indicated that yield compensation at low seeding rates was achieved by higher fertility of the side tillers and large number of grain per ear.

3.3 Basis of compensatory response

Study on soyabean during normal or better growing seasons showed compensation for yield within and across the row from gaps (Pepper and Walker, 1988). They found that stand reduction of 63% yielded 55% as much as control plots with full stands. This indicated a non-proportional yield decrease to the stand reduction whereby there was a compensation for yield of missing plants.

Conditions supporting good vegetative development early in the season would logically enhance the ability of the soyabean to compensate for deficient stands through the development of larger plants with more branches. Ultimately, through the production of more pods per plant, soyabean can compensate for yield of those plants missing from the stand (Wilcox, 1979; Willmot, 1986).

The finding of Pepper and Walker (1988) that ANOVA for yield did not indicate cultivar X gap interaction emphasized that soyabean yield compensation in a deficient stand was not influenced by the growth habit (determinate vs indeterminate) of the plant. However, they suspected that had the early growing precipitation and temperature not been favorable, then season stress could have limited vegetative expansion of canopy and there might have been a different response.

4. Changes on soil physical conditions by tillage

4.1 Aggregate size distribution

The mechanical action of the tillage implements influenced the sizes of aggregates formed in the seedbed. The suitability of tillage system to create a favorable seedbed for the crop depends on soil moisture, texture and structure before tillage. However, to obtain a suitable seedbed as described by Håkansson and von Polgár (1984) in model experiment, in field condition it may require a high number of tillage or harrowing passes. However, they suggested that if seeds were placed on a moderately compacted seedbed containing ≥ 5 % (w/w) of plant available water good emergence can be expected if the seedbed provides a good protection against evaporation. This criteria for good crop emergence need correct timing and beneficial actions of tillage and seeding implements to the soil.

In the present study (II), stubble cultivation to 13 cm depth formed greater proportion of > 5 mm and conversely lower proportion of 2-5 and < 2 mm aggregates at seedbed surface whereas lower proportion of 2-5 mm in the deeper seedbed layer compared to mouldboard ploughing to 25 cm depth. This indicates that mouldboard ploughing in autumn could have exposed deeper layer or furrow slice to the frost action that enhanced natural breakage of the soil to finer aggregates than by stubble tillage. Despite coarser seedbed surface in stubble cultivation, percent emergence was similar to conventional tillage, but grain yield was higher in the stubble tillage. This may be attributed to findings of Rydberg and Öckerman (1987) that this stubble (ploughless) tillage gave greater reduction in evaporation as compared with conventional tillage when a dry period follows a wet one, a somewhat similar condition to the present study. This reduction in evaporation could have enhanced seedling vigour in this treatment necessary for yield compensation. This phenomena may also have exhibited findings of Delroy and Bowden (1986) and Mason and Fischer (1986). They found that when there is an initially high early vegetative growth in a conventionally prepared seedbed, soil moisture reserve may be depleted prior to the completion of grain fill; thus lowering both the harvest and maximum grain yield.

Direct drilling (Site 2, II) produced a seedbed with greater proportion (more than 50 percent) of > 5 mm whereas lower percentage of 2-5 and < 2 mm aggregates compared with conventional ploughing and stubble cultivation. Soil disruption in direct drilling depends mainly on the action of the coulters and when soil surface is dry and stubble roots present, large clods are normally present. Lower emergence observed with direct drilling could be due to mechanical obstruction from the big clods resulting in slower early growth and reduced seedling vigour, a commomly observed phenomena in direct drilled crops (Gates et al., 1981; Cornish, 1985; Mason and Fischer, 1986). Several workers reported that bulk density (Douglas et al., 1980; Rasmussen, 1981) or soil strength (Van Quwerkerk and Boone, 1970; Pidgeon and Soane, 1977; Cordier et al., 1979; Pollard et al., 1981; Ellis et al., 1977, 1982) in the Ap-horizon are greater after direct drilling than after ploughing. This however, consequently produced more abundant roots in the surface layer of direct drilled soil (Drew and Saker, 1978). Despite great reduction in plant emegence with direct drilling in this experiment, grain yield were similar for all tillages. This occurence might show that when soil moisture is adequately replenished in the top portion of the soil profile, direct drilled plants may utilize the improved soil moisture and increase grain yield to levels attained by other tillages either through increased number of ears m^{-2}, number of grains per ear, increased 1000-grain weight or their combination.

From time-domain reflectometry measurements, harrowing thrice (in Site 1, II) reduced the rate of water loss below 5 cm layer as compared to 0 harrowing. Secondary tillage such as harrowing which is primarily intended to reduce aggregate sizes also tend to sort the bigger aggregates onto the seedbed surface while the smaller ones to the bottom resulting in a gradient in structure through the seedbed (Kritz, 1983). This will increase porosity and roughness in the seedbed surface and the reverse in the seedbed bottom consequently reducing moisture loss by evaporation. Heinonen (1985) reported that on heavy clay soil, increasing the intensity of harrowing and rolling reduced evaporation rate.

4.2 Soil matric potential

In paper I, tillage by ploughing and harrowing in 10 cm depth resulted to a consistently higher matric potential as well as gravimetric moisture content at 10 cm depth and below compared to non-tilled plots during measurement period 6-21 days after draining (DAD). This indicated that soil surface mulch produced by tillage reduced moisture loss by evaporation. Nevertheless, the change in matric potential at 5 cm was similar for tilled and non-tilled plots. Tillage also prevented the formation of deep wide cracks as compared to the no-till treatment. Unluckily, no further measurement on either matric potential or gravimetric water content were taken after 21 DAD thus, soil-mulching may also be temporary.

Reflooding and with additional disturbance from weeding of a dried and cracked previously ploughed and harrowed plot resulted in the formation of surface crust and less intense cracking. The change in matric potential with time in the two non-tilled plots (Experiment A vs Experiment B) at 10-cm depth was similar but only until 11 DAD, a pattern also observed in thermal diffusivity. But later as drying progresses, the non-tilled Experiment B, with surface crust and less intense cracking, dried much more slowly and resembled the tilled treatment in Experiment A. This result indicated that tillage of the soil surface or the formation of surface crust both reduced the rate of evaporation but the latter was only evident during later drying. Other research findings showed that formation of a 2 cm dry mulch layer (Heinonen, 1985) or a 2 cm of 1-2 mm screened sand mulch (Gardner and Fireman, 1958) both decreased evaporation rate.

4.3 Thermal diffusivity

The direct effect of tillage systems on soil temperature focused on soil exposure to insulation and the alteration of the reflection coefficient or albedo. Indirectly, tillage-induced changes in soil structure and soil moisture affect thermal conductivity and diffusivity (Babalola et al., 1993).

In Experiment A, paper I, tillage decreased mean thermal diffusivity, Dh, measured at 0-15 cm depth over the 7-21 days after draining (DAD) with values of Dh = $6.6 \pm 0.9 \times 10^{-7}$ m^2 s^{-1} and $4.4 \pm 0.05 \times 10^{-7}$ m^2 s^{-1}, for no-till and tilled soil respectively. There was a higher thermal diffusivity at low-moistured/non-tilled plots whereas the converse was true for the high-moistured/tilled treatments. Potter et al. (1985) also observed an increase in thermal diffusivity with decreasing water content.

On the other hand, there was a lower mean thermal diffusivity in the non-tilled treatment in Experiment B, paper I, than in non-tilled treatment in Experiment A, I ($2.8 \pm 0.1 \times 10^{-7}$ m^2 s^{-1} and $6.6 \pm 0.9 \times 10^{-7}$ m^2 s^{-1}, respectively). Water contents were similar in these two treatments but only until 11 DAD. Thereafter, there was less intense drying in Experiment B due to minimal cracking combined with surface crust whereas the no-till soil in Experiment A cracked severely (~ 3 cm wide, 10 cm deep) consequently drying faster.

Moreover, the amplitude in surface temperature is inversely proportional to the thermal conductivity and the heat capacity of the soil (Koorevaar et al., 1983). Since tilled soil as plow-till (mouldboard plow, disc plow, Rome-plow, rotovator and harrow) had higher maximum and lower minimum temperature than no-till soil (Babalola et al., 1993) ploughing and harrowing in the present experiment may result in higher amplitude compared to no-till corresponding to lower conductivity or diffusivity in tilled soil.

5. Influence of seed coulters and presswheels on crop establishment

The adaptability of root system to soil conditions produced by direct drilling differs between plant species. However, Whiteley and Dexter (1982) indicated that changes in sowing equipment may be a simpler solution to overcome this root adaptability problem. The first and most critical aspect of crop establishment depends on whether the seed is sown at optimum depth and is covered by the soil.

In paper II, to determine the extent to which seeds were placed in the seedbed bottom and relative to each other horizontally, and to assess the consequent effects on plant emergence, comparisons of three seed coulters; Nordsten, JB Special and Ekoodlaren in sites 1 and 2 were made :

The Nordsten, a hoe-type coulter, successfully placed most of the seeds at the firm seedbed bottom and after sowing it slightly recompacted the soil with its presswheels. This resulted in highest plant emergence with narrowest distance between plants. On the other hand, the JB Special (a duckfoot-type coulter) placed higher proportion of seeds in the topmost seedbed layer resulting in significantly lowest emergence compared to Nordsten and "Ekoodlaren". A common characteristic of air drills, JB as one, is to blow some seeds farther from the desired depth, an effect derived from high air current flowing through the drill. McLeod et al. (1992) suggested that seeding rate should be adjusted upward if an air-drill is to be used in seeding on stubble. The distance between plants with the JB was wider than with the Nordsten. "Ekoodlaren", also a duckfoot-type coulter, placed seeds at the seedbed bottom as the Nordsten, but it formed deeper loose seedbed with rougher surface as compared to the other coulters. The formation of deeper loose seedbed may partly be due to deeper working depth of the machine. This may have enhanced moisture loss by evaporation resulting in percentage emergence intermediate between Nordsten and JB Special. Distance between plants from "Ekoodlaren" is similar to the Nordsten.

JB Special with the least plant emergence had grain yield higher in site 1 and similar in site 2 as compared to the other two coulters. A faster early growth contributing to compensatory reaction of plants in the JB plots could have accounted for this yield difference.

A prototype relay seeder used in Experiment B, paper I, was a coulter disc that cut a slot and scraped some soil away before dropping the seeds from a rotating perforated drum then covering the seeds with soil. It was successful only when the seeds were sown at soil matric potential of -0.01 to -0.05 MPa (3 to 5 DAD). Primarily designed for wet soil it was only able to deliver seeds at a maximum of 2 cm depth at 7 DAD when on this day the matric potential at 5 cm was -0.05 MPa but at 2 cm was already -1.2 MPa. Sowing at 7 DAD was too late for this machine and very low plant emergence (only about 20 %) was observed.

6. Prediction of mungbean germination

Fyfield ang Gregory (1989) derived two model equations to predict mungbean germination from controlled-environment studies on the combined effect of constant temperature and water potential.

$(-1.7 \leq \psi_w \leq 0$ MPa and $10.1 < T \leq 40$ °C)

where: Gt_{50} = median germination time in days
ψ_w = osmotically created water potential
T = temperature

Equation 2: $Gf = 112 - 38\,(Gt_{50}) + 9.5\,(Gt_{50})^2 - 0.9\,(Gt_{50})^3$
This equation described the correlation between Gt_{50} and final percentage germination (G_f).

Using these equations, they predicted germination percentages from field measured soil matric potential (assuming $\psi_m \equiv \psi_w$) and daily mean temperature recorded at 5 cm depth. They found that in moist soil ($\psi_m > -0.1$ MPa), observed percentages were slightly higher than those predicted. However, when the soil had dried to < -0.7 MPa, observed percentages were lower than predicted. They indicated probable importance of seed-soil contact such that better all-round contact in the field occurred in the moist soil enhancing germination whilst in drier soil a rapid soil water depletion near the seed inhibited germination to a greater extent than expected.

7. Plant growth pattern at varying densities

Tillage-induced changes in soil properties do not always reflect tillage effects on crop performance. This may be attributed to compounding influences of other environmental factors as well as the physiological traits of the crops. The ultimate potential yield of a crop is set by its genetic capacity and the amount of solar radiation it receives. Plant growth defined as the increase in its size could be studied in terms of increase in either dry weight or in dimensions which arose as a consequence of the formation of new cells, the expansion of the constituent cells, and the production of assimilates. Commonly, the rate of growth is expressed as the increase in weight, volume, area, or length per unit time (Payne and Gregory, 1988).

7.1 Leaf area index

Once a crop is established, for most of a crop's life, the leaves are the main plant organs intercepting sunlight and converting it to chemical energy and then to dry matter. Maximum crop growth is therefore highly dependent on the expansion of leaf area to intercept the maximum amount of radiation. For many crops, a leaf area index (total area of leaves per unit area of ground) of about 3-5 is necessary to intercept 80-90 percent of the incident, photosynthetically active radiation. Expansion of leaf area depends on the number of leaves, the rate at which they expand and their final size and these are primarily affected by temperature, plant water stress, and nutrient availability (Payne and Gregory, 1988).

From III, maximum leaf area index (LAI) of 3 for soyabean and 2 for mungbean was reached at about 50 days after sowing or at early grain filling stage from plots with 0.40 million plants per hectare (M plants ha^{-1}). Plant populations of 0.4, 0.2 and 0.13 M plants ha^{-1} were from row spacings of 0.25, 0.50 and 0.75 m with 10 plants per linear meter. During plant growth for both crops, there was a consistently lower LAI at 0.20 and 0.13 as compared to 0.4 M plants ha^{-1}. After the maximum LAI was reached it decreased to zero in soyabean but by only 17 % in mungbean. For pearl millet, Garg et al. (1993) reported that decreasing the plant population to 0.145 M plants ha^{-1} reduced leaf area index. LAI varied with plant species such that the maximum for soyabean was 1.7 times greater than mungbean.

7.2 Photosynthetic efficiency

Yield is normally not equivalent to total dry matter production but only to a certain fraction of it. This may vary both with the plant genotype and the environment. An increase of this fraction can be achieved by some method of plant husbandry as well as plant breeding. Still unresolved problems as to this effects include photorespiration, compensation responses of crops and attainment of potential photosynthetic production. Limits has perhaps been reached for certain crops at certain stages of development but there seems to exist a fairly wide gap between what may be produced theoretically and what is actually achieved. The reasons for this discrepancy may be lack of water or nutrients, internal factors such as adequate assimilate distribution and inhibited rate of photosynthesis, or both (Ermilov, 1962).

Photosynthetic efficiency relates to LAI. Without high LAI values, the useful light cannot be intercepted at efficiently low levels of illumination. From paper III, the efficiencies of conversion of absorbed photosynthetically active radiation (PAR) into shoot dry matter, as an average over all densities, was 1.4 g MJ^{-1} in soyabean and 1.6 g MJ^{-1} in mungbean from emergence to 61 DAS. Although mungbean had a lower LAI the amount of PAR absorbed was similar for both species because mungbean had greater extinction coefficient than soyabean. There was a decrease of the seasonal average conversion efficiency in soyabean to about half due to very little dry matter accumulation from 61 DAS to harvest caused by water stress at late reproductive stage.

Goyne et al. (1993) reported that radiation use efficiency based on absorbed PAR and above-ground dry matter was not affected by the time of sowing but did vary between barley cultivars. Araus et al.(1993) found that in durum wheat, most of the photosynthates in the grain come from ear parts and not from the flag leaf whereas higher water use efficiency was also observed in ear parts than the flag leaf.

7.3 Dry matter production

The concept of crop growth rate (C, net dry matter production) from the use of leaf area was pioneered by English scientists who applied the techniques of 'growth analysis' to agricultural communities. It was defined as the net assimilation rate of leaves (E, mean rate of net photosynthesis of all leaves) times the leaf area index (LAI) or C = E * LAI.

For crops that produce their seeds at almost the same time (determinate), leaf growth ceases shortly before or soon after flowering, and thereafter photosynthesis depends mainly on the persistence of existing leaves. Moreover, once fully extended, a leaf does not remain photosynthetically active for long, and in barley it was found to decrease rapidly only five days after complete expansion (Littleton, 1978).

During approximately linear phase of growth [26-61 days after sowing (DAS) for a 105-day determinate soyabean and 26-68 DAS for a 65-day determinate type mungbean] crop growth rates were similar (III). Mungbean accumulated dry matter until maturity but soyabean accumulated little dry matter between 61 DAS (the time of maximum dry matter accumulation in soyabean) and maturity due to severe water stress. With time both crops accumulated consistently increasing amount of dry matter with increase in plant density.

8. Effect of plant density on grain yield production

From paper III, highest grain yield in soyabean was obtained in the intermediate plant population (0.20 M plants ha^{-1}) as compared to 0.4 and 0.13 M plants ha^{-1}. However, forage yield decreased with decreasing plant densities. For soyabean, mean grain mass and number of pods plant^{-1} were both higher in the 0.2 and 0.13 M plants ha^{-1}, but this did not compensate sufficiently to increase yield to equal that from 0.40 M plants ha^{-1}. Plant population did not affect the number of grains per pod for soyabean. In mungbean, highest grain and forage yield were from the 0.40 M plant ha^{-1}, and generally mean grain mass, number of pods plant^{-1} and number of grains per pod increased as plant density increased.

In Sweden (II) higher barley grain yield was obtained with less dense population, 3.1 than 3.8 M plants ha^{-1} from the use of JB and Nordsten seed coulter, respectively. Production of more tillers with filled grains or more efficient translocation of assimilates from vegetative to reproductive growth resulting to either increased number of heads/m^2 or number of grains per head with less plants could have accounted for this yield increase.

9. Conclusion

In both countries, shallow tillage either to 10 cm or 13 cm depth enhanced evaporation control at layers below the tilled zone by the formation of aggregates that created gradient in seedbed structure. Tillage retained higher matric potential and gravimetric moisture content and reduced thermal diffusivity at depth below the tilled zone as compared to no-till treatment.

Timely crop establishment is very necessary to utilize the residual soil moisture from a preceding rice crop in the Philippines which in this particular experiment appeared to be about 6 to 8 days after draining of a saturated soil but at about 3 to 7 days after draining in soils where surface crusting is expected. However, rates of soil drying may vary from different locations, soil types, weather conditions and others factors, and these may need further studies. Residual soil moisture from the preceding winter as well as optimum solar radiation may be fully utilized in Sweden by a tillage system that would allow early sowing with good expected plant emergence.

Sowing at 6 to 8 days after draining when matric potential range between -0.01 to -0.05 MPa for non-tilled and -0.01 to -0.08 MPa for tilled treatments are favorable for > 50 % plant emergence in a Vertic Tropaquept soil. To ensure optimum emergence, in this case increased sowing rate would be needed, whereas residue mulch could probably reduce moisture loss and lengthen the crop establishment period.

In Sweden, stubble cultivation resulted in grain yield that was better or similar compared with mouldboard ploughing. Reduced tillage such as stubble cultivation or direct drilling may be a better alternative to conventional tillage from lower cost of fuel and energy in addition to improved soil structure but may only be to certain point in time when again the mouldboard ploughing will be necessary.

Harrowing which tend to sort the bigger aggregates onto the seedbed surface and the smaller ones to the bottom may have improved evaporation control whereas the use of presswheels could enhance better seed-soil contact and benefits can be derived when used in appropriate conditions. However, this effect from the Nordsten was offset by too many plants whereby a combination of appropriate seed placement and seeding rate might improve crop performance.

Increasing plant population for both soyabean and mungbean increased leaf area index, interception of photosynthetically active radiation, crop growth rate during linear phase of growth, and forage yield. However, for soyabean highest grain yield was obtained in the 0.20

M plants ha^{-1} while higher mean grain mass and number of pods per plant were observed in the 0.20 and 0.13 compared with 0.40 M plants ha^{-1}. Mungbean grain yield increased by increasing plant density. Thus, plant species/genotype can be selected for a particular cropping season to optimize its traits for improved production.

Soyabean was able to translocate its assimilate efficiently from vegetative tissue to grain compensating for reduced photosynthesis during reproductive growth. Higher plant density can result in heavier grain yield even with severe water stress during reproductive growth, and confirm the need for good establishment for maximum yield of dryland crops grown after rice. With a favorable weather, long duration crop may have higher potential yield.

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PAPER I

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Effects of tillage, seeding method and time of sowing on the establishment of mungbean in drying, previously puddled soil

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ABSTRACT

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Two field experiments were conducted on small plots in the Philippines to determine the effects of tillage, seeding method and time of sowing on the establishment of mungbean (*Vigna radiata* (L.) Wilczek cv. IPB-M79-17-79) in seedbeds created in drying soil that had been puddled as for an immediately preceding wetland rice crop.

Conditions following rice were simulated by flooding, puddling and then draining the plots. Mungbean was sown at 2–14 days after draining (DAD) as the soil dried. In one experiment, seeds were sown manually into plots that were either non-tilled or for which the surface 10 cm had been ploughed and harrowed. In a second experiment, manual sowing into non-tilled plots was compared with prototype machine seeding. Soil matric potential and temperature were monitored throughout the experiments, and germination and seedling emergence recorded.

Surface cultivation slowed the rate of water loss from depths below 5 cm and resulted in lower thermal diffusivity than in non-tilled soil. Germination results indicated that following drainage of a seedbed in previously puddled soil, manual sowing at a depth of 5 cm could be delayed until 8 DAD (while soil matric potentials remained > -0.1 MPa) without a significant reduction in seed germination. The seeding machine was quicker and easier to use, but its constraint of shallow sowing (maximum depth 2 cm) meant that sowing could be delayed only to 5 DAD before germination and emergence were inhibited. Predictions of germination from measured values of temperature and water potential were made using equations derived from controlled-environment studies. Differences from germination observed could probably be accounted for by seed/soil/water contact effects, which appeared to be especially important in dry soil (< -0.7 MPa). Subsequent seedling emergence was, however, often severely restricted in non-tilled soil by soil mechanical constraints in the drying, strengthening seedbed. In the first experiment, these conditions were alleviated by the cultivation treatment; in the second, disturbance of surface soil before drainage resulted in greater emergence and faster seedling growth.

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INTRODUCTION

In wetland rice-growing regions of South and Southeast Asia, the short post-monsoon (dry) season allows a dryland (upland) crop to be grown after rice. Since the non-rice crop is dependent primarily on residual soil moisture, the ideal species are those of short duration, such as grain legumes (Zandstra, 1982), e.g. mungbean, soyabean and cowpea. Traditionally, such crops have been grown with low inputs and low management, and have consequently produced low yields (Jayasuriya and Maranan, 1982). Nevertheless, their economic importance to the small farmer can be high and production is encouraged by governments in Southeast Asia so as to reduce imports.

A major constraint to the production of dryland crops after wetland rice is the problem of establishment in a poorly structured seedbed which may be too wet, too dry or too hot. The timing of sowing is critical if good establishment and subsequent growth are to be achieved. After wetland rice, the soil will initially be wet and in a reduced condition, and sowing too early may inhibit germination due to poor aeration and fungal attack. A delay in sowing, however, increases the risk that the seedbed will become too dry for successful germination. Moreover, as the puddled soil dries it may become compact and hard, thus inhibiting both emergence and root growth. Soil mechanical constraints and lack of aeration can both be alleviated by tillage, although this may accelerate topsoil moisture loss (Zandstra, 1982) and increase the time interval between rice harvest and seeding of the dryland crop, both of which may lead to reduced emergence. Zero-tillage could therefore be beneficial (Syarifuddin, 1982), as could relay cropping (sowing the dryland crop after the soil has been drained, but before the rice is harvested). An additional problem that may be encountered is soil temperature, which may be high enough to inhibit seedling growth.

A previous paper (Fyfield and Gregory, 1989) reported the results of controlled-environment studies on the combined effects of temperature and water potential on the germination and emergence of mungbean (*Vigna radiata* (L.) Wilczek, cv. IPB-M79-17-79). Equations derived to model the effects of temperature and water potential on germination, studied using an osmoticum technique, were used to make predictions for mungbean sown in soil columns. Differences between observed and predicted germination suggested the additional importance of seed/soil/water contact in influencing germination in soil.

The present paper reports subsequent field studies conducted at the International Rice Research Institute (I.R.R.I.) in the Philippines on the effects of tillage, seeding method (manual and machine) and time of sowing on the establishment of mungbean in a drying, previously puddled soil. One aim was to compare field germination with predictions made using the controlled-environment model. A second aim was to study the effects of sowing delay on germination and emergence in both non-tilled and tilled seedbeds to provide guidelines as to the optimum soil conditions and time of sowing for mungbean after wetland rice.

MATERIALS AND METHODS

Two field studies were made at I.R.R.I. on a Vertic Tropaquept soil (silty clay loam overlying silty clay) during the dry season of February/March 1987.

Experiment A

The first experiment was designed to study the effects of tillage and sowing delay on mungbean germination and emergence.

Conditions following wetland rice were simulated by flooding, puddling and then draining two adjacent 5 × 10-m plots, each enclosed by low earth mounds or bunds. Each plot was divided into three strips and each strip into sub-plots 1.5 m square, giving three replicates of two tillage treatments and three sowing dates.

At 2, 6 and 8 days after draining (DAD), fungicide-treated mungbean (cv. IPB-M79-17-79) seeds were sown manually at a depth of 5 cm and at an inter-row spacing of 10 cm in non-tilled (T0) sub-plots. At 6, 8 and 13 DAD, similar sowings were carried out in tilled (T1) sub-plots whose surface 10 cm had been cultivated by ploughing and harrowing at 6 DAD.

Measurements of soil temperature were made every 2 h (and occasionally hourly) using thermistors at depths of 5, 10 and 15 cm in one sub-plot per tillage treatment (three replicates at each depth). Together with an additional thermistor positioned on the soil surface, these were connected to a Grant recorder held inside an adapted Stevenson's screen and mean soil temperature was calculated from the three replicate thermistors at each depth. Measurements of temperature at the soil surface were also made on one occasion using an infrared thermometer.

Air temperature, solar radiation, rainfall, relative humidity and pan evaporation rate were all measured daily at the I.R.R.I. Wetland Meteorological Station, ~0.5 km from the experiment site.

To measure the rate of soil drying 6 PVC tubes, consisting of 15 × 1.0-cm deep rings (10 cm internal diameter) taped together, were pushed into each sub-plot immediately prior to the first sowing in each tillage treatment. Selected columns of soil were withdrawn daily up until 9 DAD then every 2 days (three replicates per tillage treatment) and sliced up into 15 × 1.0-cm sections. Each section was placed above a pair of Whatman No. 42 5.5-cm diameter filter papers and enclosed in a plastic bag. After 2 days equilibration in an air-conditioned room, the filter paper in immediate contact with the soil was discarded, and the other weighed, dried at 80°C and reweighed to determine its water content. Soil matric potential was then calculated using the calibration curve of Hamblin (1981), which had been verified. The gravimetric soil moisture content of each section was also measured subsequently. Mean potential and water content values for each 1.0-cm section were calculated from the three replicate columns.

The number of seedlings emerged (cotyledons which had appeared above the soil surface) was recorded daily for each sowing and mean percentage emergence calculated from the three replicates. When emergence percentage was constant, a separate germination percentage was determined by digging up all seeds in selected rows.

Experiment B

The second experiment was designed to study further the effects of sowing delay on mungbean germination and emergence in non-tilled soil, and also to compare manual sowing with a prototype seeding machine.

Plots for Experiment B were in the same field, were of similar size and were puddled at the same time as in Experiment A. After 10 days of drying, these plots were reflooded, weeded and drained, then each divided into sub-plots giving three replicates of two sowing methods and five sowing dates.

Manual sowings were made at 3, 5, 7, 10 and 14 DAD; sowings using a prototype seeding machine were made at 3, 5 and 7 DAD. The machine was a relay seeder, designed to sow legumes between rice rows after drainage, but before harvesting. It cut a slot with a coulter disc and scraped some soil away before dropping seeds from a rotating perforated drum and then covering them with soil. Since the machine's seeding rate was not constant, an approximate calibration was made by counting the number of seeds delivered in one row of each sub-plot and assuming an identical delivery rate in the remaining rows.

Measurements of soil drying rate, temperature, seed germination and emergence were made as in Experiment A, but, except for emergence, in manually sown sub-plots only.

RESULTS AND DISCUSSION

Averages of daily mean air temperature, solar radiation, relative humidity and pan evaporation rate for both experiments are given in Table 1. Total rainfall was negligible, and seedbeds dried continuously under conditions of high irradiance.

Experiment A

The soil, initially saturated, had matric potentials (ψ_m) generally > -0.005 MPa ($\sim 54\%$ gravimetric moisture content) throughout the 0–15-cm profile

TABLE 1

Summary of environmental data (values are means, except for rainfall) recorded at the I.R.R.I. Wetland Meteorological Station during Experiments A and B

Experiment	Length of experiment from initial sowing (days)	Daily mean air temperature (°C)	Solar radiation ($MJ\ m^{-2}\ day^{-1}$)	Relative humidity (%)	Pan evaporation rate ($mm\ day^{-1}$)	Total rainfall (mm)
A	26	28.7	20.3	70	6.0	1.8
B	20	26.7	21.9	68	6.5	3.8

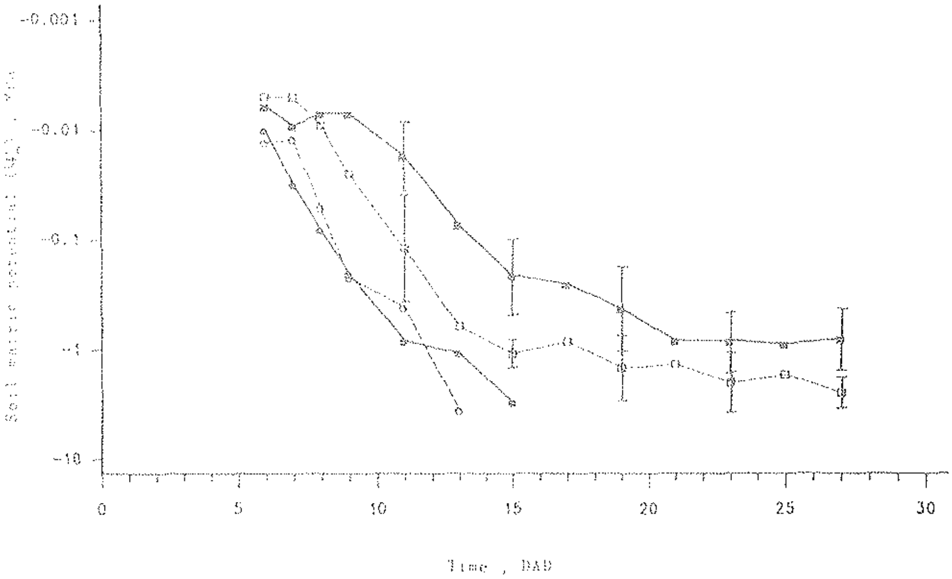

Fig. 1. Effect of tillage on the change with time of soil matric potential at depths of 5 cm (circles) and 10 cm (squares) during Experiment A, with 95% confidence intervals shown for representative points at 10 cm. Open symbols, non-tilled (T0); closed symbols, tilled (T1).

from 2 to 5 DAD. (The ψ_m range within which Hamblin's (1981) filter paper method is accurate is $-0.005 > \psi_m > -3$ MPa.) However, from 2 DAD the soil began to shrink and crack, and by 6 DAD the non-tilled sub-plots had cracks up to 3 cm wide and ~10 cm deep (approximately the depth of the puddled layer). Profiles of soil matric potential for both non-tilled (T0) and tilled (T1) sub-plots indicated slower drying below 5 cm in T1 than in T0. The change in ψ_m with time (Fig. 1) shows that at 5 cm drying was similar for T0 and T1, which each dried to < -3 MPa by 15 DAD. At 10 cm and below, however, ψ_m in tilled soil was consistently higher than in non-tilled soil from 8 DAD (i.e. 2 days after tillage) until the end of the experiment. The two main plots had been assumed to be identical, but unfortunately a difference in elevation of a few centimeters between them caused different drying rates and thus considerable variation between what had been considered replicate sub-plots. Effects of tillage on soil matric potentials at 10 cm were therefore not always significant (Fig. 1; $P=0.05$), but the trend remained clear. The same trend occurred with gravimetric soil moisture content in that the water content at 10 cm was greater for T1 soil than for T0, and the values from both tillage treatments at 5 and 10 cm appeared to form a single soil moisture characteristic curve. The likely explanation is that cultivation removed the cracks and reduced the surface hydraulic conductivity, such that whilst the top 5 cm still dried at the same rate, the rate of water loss from the soil below was decreased. Cultivation would also reduce pore continuity between the tilled surface layer and the undisturbed soil beneath, creating, in effect, a dry surface mulch which acts as an evaporation barrier by preventing the capillary rise of water (see Hemonen, 1989).

An example of diurnal temperature fluctuations at 5- and 15-cm depths in the two tillage treatments is shown in Fig. 2 (hourly measurements made at 9 DAD). For both T0 and T1, the amplitude at 15 cm was clearly smaller than that at 5 cm and the temperature wave lagged. Similarly, for T1 the amplitude was smaller than that for T0 at both depths and the temperature wave

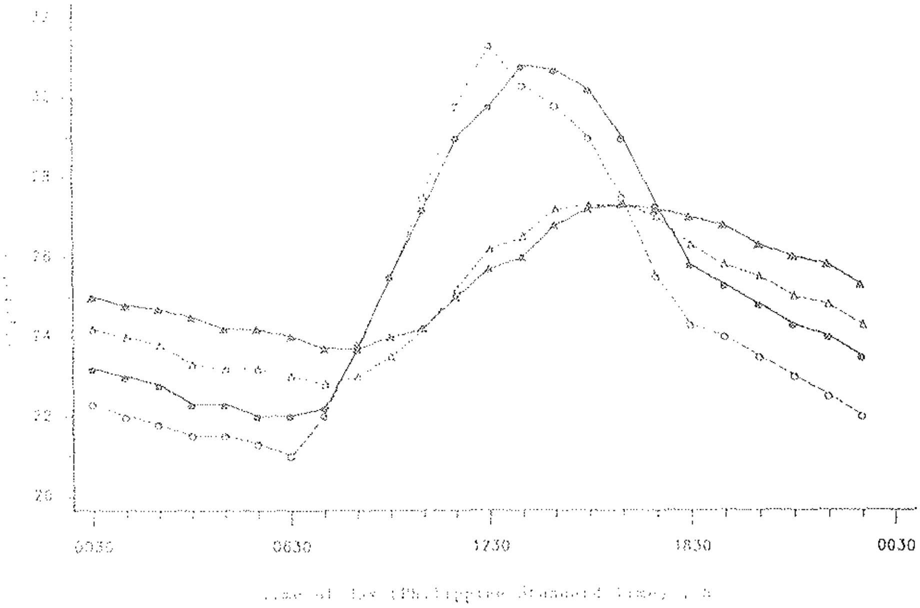

Fig. 2. Effect of tillage on the diurnal fluctuation in soil temperature at depths of 5 cm (circles) and 15 cm (triangles) recorded at 9 DAD in Experiment A. Open symbols, T0; closed symbols, T1.

again lagged. The damping effect with depth was used to calculate thermal diffusivity (D_h) for the two tillage treatments (Fig. 3). Mean thermal diffusivity taken over the period 7–14 DAD was significantly higher ($P=0.05$) for T0 than for T1 ($D_h=6.6\pm0.9$ and $4.4\pm0.5\times10^{-7}$ m^2 s^{-1}, respectively), a result similar to that obtained by Potter et al. (1985). These workers also observed an increase in thermal diffusivity with decreasing soil water content, a trend evident in Fig. 3 as the T0 sub-plots rapidly dried out between 4 and 8 DAD. Measurements from the single surface thermistor were found to agree with those obtained using the infrared thermometer. The latter also showed no difference between the surface temperatures of tilled and non-tilled soil.

When the fate of seeds in Experiment A was determined (Table 2), it was evident that, except for the 13 DAD sowing when ψ_m had dried to -1.1 MPa, germination was high in all treatments. However, subsequent emergence was restricted by soil physical constraints, especially following the 2 DAD sowing when the soil surface hardened as it dried such that seedlings were only able to emerge where cracks occurred. Seedlings unable to locate a crack remained below the hard surface, or sometimes emerged without their cotyledons due to fracture of the hypocotyl. Similar observations were reported by Rathore et al. (1981), who examined the effect of soil crusting on soyabean emergence. Clearly, it was necessary to penetrate the hard soil surface in order to

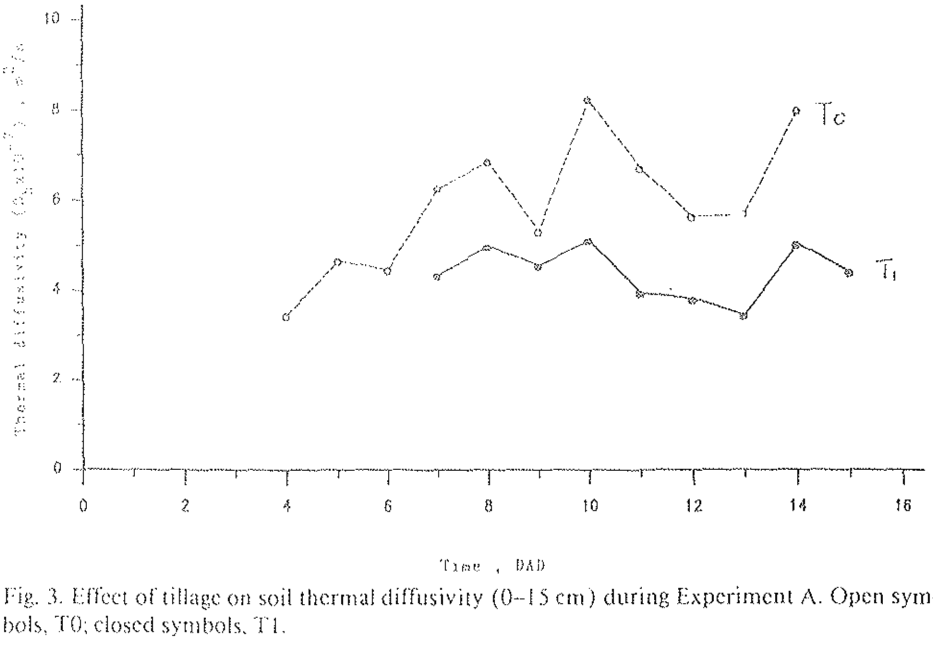

Fig. 3. Effect of tillage on soil thermal diffusivity (0–15 cm) during Experiment A. Open symbols, T0; closed symbols, T1.

TABLE 2

The fate of mungbean seeds in non-tilled (T0) and tilled (T1) soil in Experiments A and B (determined 7–8 days after sowing), with soil matric potential (ψ_m) at 5-cm depth at sowing (daily mean soil temperature at 5 cm was ~25°C in Experiment A and 29°C in Experiment B). NR = not recorded

Experiment	Tillage treatment	Time of sowing (DAD)	ψ_m (MPa)	Germinated seeds (%)			Non-germinated seeds (%)		
				Seedlings emerged	Seeds germinated but not emerged	Total	Damaged by pathogens	Swollen but not germinated	Tota
A	T0	2	> −0.005	22	63	85	13	NR	15
		6	−0.01	50	40	90	7	NR	10
		8	−0.05	52	35	87	5	NR	13
	T1	6	−0.01	67	30	97	2	NR	3
		8	−0.08	85	13	98	0	NR	2
		13	−1.1	15	17	32	20	NR	68
B	T0	3	−0.01	85	13	98	1	1	2
		5	−0.03	92	3	95	3	1	5
		7	−0.05	81	7	88	3	5	12
		10	−0.75	23	28	51	16	18	49
		14	−1.2	1	13	14	21	30	86

carry out the later T0 sowings and this improved subsequent emergence. The action of tillage in further breaking up the hard compact soil appeared to enhance emergence even more. Sharma et al. (1988) reported no effect of tillage on mungbean emergence in a lowland rice soil, but in their experiments soil moisture was apparently not limiting.

Experiment B

As in Experiment A, the two main plots in the second experiment also dried out at slightly different rates, thus increasing the variability between replicate sub-plots. However, the pattern of drying differed from the first experiment in that instead of deep wide cracks appearing due to soil shrinkage, only the surface 1 cm formed a hard broken crust and the cracking beneath was much less severe. This resulted in the creation of a much better seedbed and may have been due to the slight difference in plot preparation prior to the two experiments. The reflooding of dry cracked plots and additional disturbance of the top 1 cm of soil during weeding before Experiment B resulted in only this surface layer crusting, which prevented both extensive cracking and hardening of the soil beneath. It also slowed the rate of water loss from below 5-cm depth. A comparison of the soil drying curve at 10 cm for Experiment B with those for tilled and non-tilled treatments from Experiment A is shown in Fig. 4. The curve for Experiment B is similar to the non-tilled treatment of Experiment A before 11 DAD, but thereafter more closely resembles that of the tilled treatment.

Mean thermal diffusivity in Experiment B, taken over the period 7–21 DAD, was significantly lower ($P=0.05$) than for non-tilled soil in Experiment A (2.8 ± 0.1 compared with $6.6 \pm 0.9 \times 10^{-7}$ m^2 s^{-1}). Since soil water contents were similar in both experiments, the difference may again be ascribed to soil structural differences.

In Experiment B, there was less soil mechanical constraint to mungbean emergence than in non-tilled soil in Experiment A, resulting in a much higher percentage emergence of the germinated seed in the early manual sowings than in Experiment A (Table 2). The effect of a delay in sowing on germination and emergence for non-tilled soil in the two experiments is shown in Fig. 5. Whereas germination in Experiments A and B was similar, emergence in Experiment A (particularly the sowings at 2 and 6 DAD) was considerably less. Emergence rates were also faster than in Experiment A and shoot growth, although not measured, was visually greater. This may be an effect partly of increased soil temperature: the daily mean at 5-cm depth on the day of sowing averaged ~29°C compared with 25°C in Experiment A. However, since soil matric potentials at 5 cm were similar at the time of the 3–7 DAD sowings to those in Experiment A, this enhanced establishment is probably mainly due

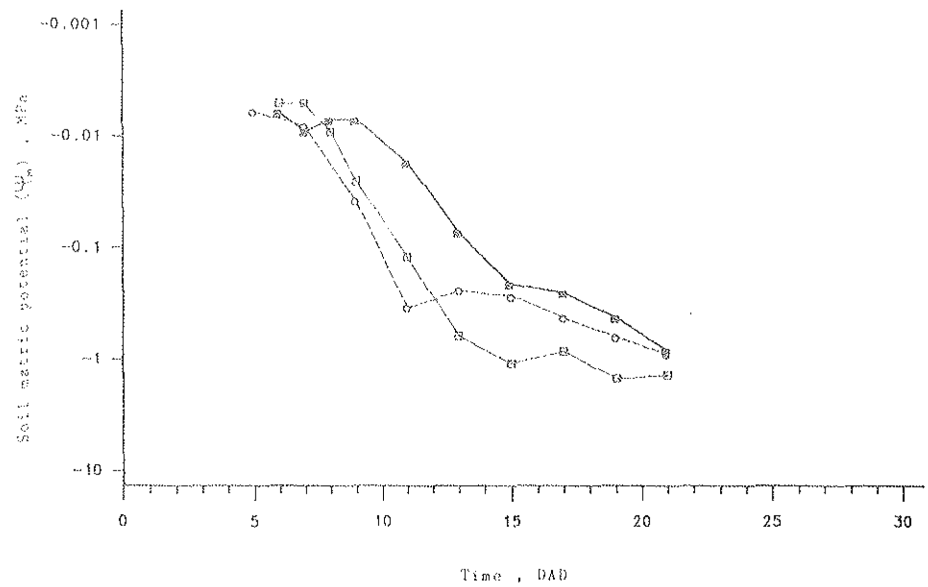

Fig. 4. Change with time of soil matric potential at 10-cm depth in non-tilled soil in Experiment B (○), as compared with both non-tilled (□) and tilled (▩) soil in Experiment A.

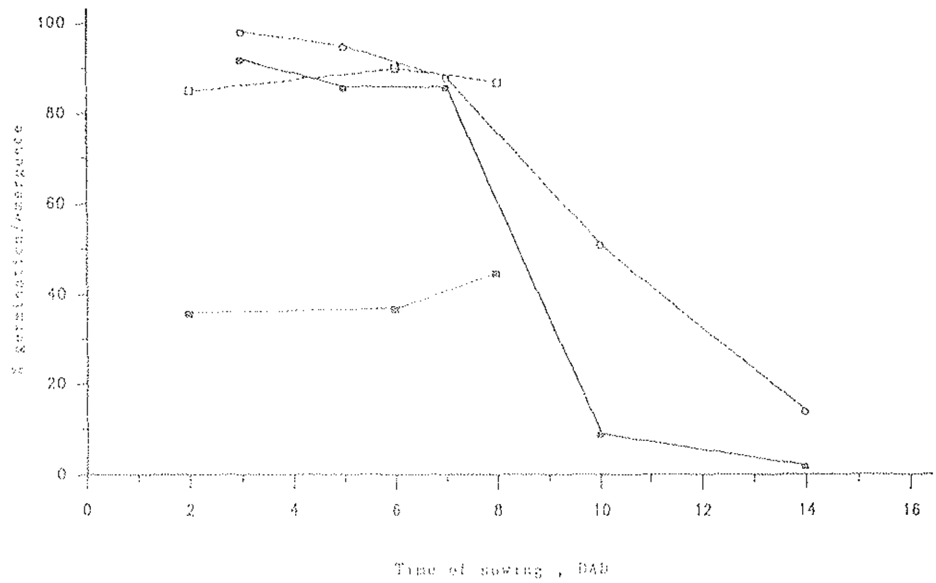

Fig. 5. Effect of delay in sowing on mungbean germination (open symbols) and seedling emergence (closed symbols) for non-tilled soil during Experiments A (squares) and B (circles).

to the lower mechanical strength of the seedbed. At the two later sowings (10 and 14 DAD) in Experiment B, the drier soil resulted in greatly reduced germination and emergence (Fig. 5). Table 2 shows that a proportion of the non-germinated seeds had imbibed water, but insufficient for germination; many thus became vulnerable to attack by pathogens. Some of the seedlings which emerged from these drier sub-plots still had their cotyledons partly encased by the seed testa, which may restrict subsequent growth.

From sowings made by the seeder (Fig. 6), emergence was high at 3 and 5 DAD, and not significantly different from comparable manual sowings. However, at 7 DAD machine-sown seeds had significantly lower emergence ($P=0.05$), despite the wide variation shown in Fig. 6. The reason for this low emergence may be that the machine, a relay seeder, was primarily designed for use in wet soil, and even when weighted or physically held down appeared able to deliver the seed at a maximum depth of only 2 cm. Since soil at 2 cm dried faster than at 5 cm (the sowing depth in the manual sub-plots), a matric potential inhibitory to germination and emergence would have been reached sooner: at 7 DAD ψ_m at 5 cm was -0.05 MPa, whereas at 2 cm it was -1.2 MPa. Thus sowing at 7 DAD is too late for this seeding machine. The uneven seed delivery rate means that the emergence percentages for the seeder-sown sub-plots are only approximate; a total percentage germination could not be calculated as accurately as in the manually sown sub-plots and therefore was

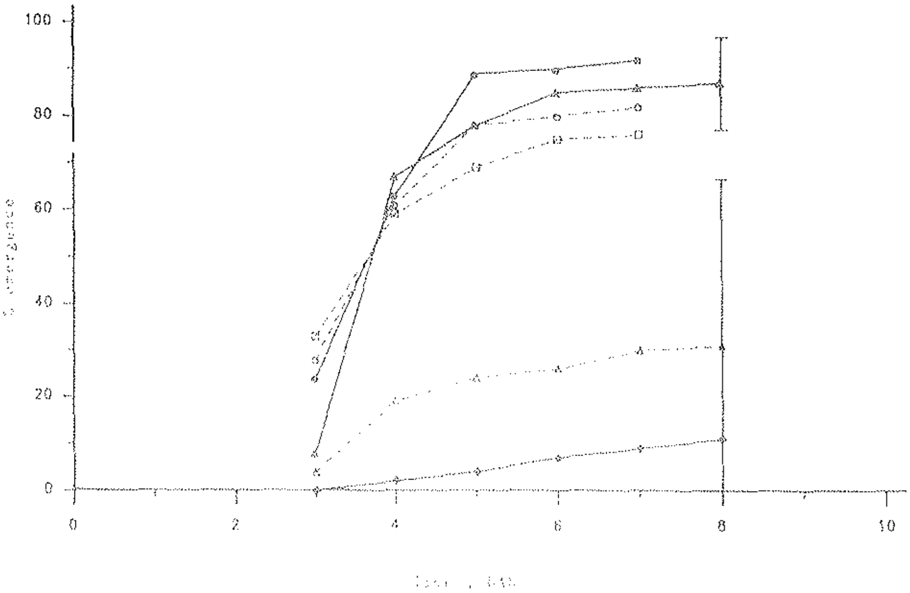

Fig. 6. Mungbean emergence in Experiment B for machine sowings (open symbols) at 3 (○), 5 (□) and 7 DAD (△), and for manual sowings (closed symbols) at 3 (●), 7 (▲) and 10 DAD (◆), with 95% confidence intervals shown for the 7 DAD sowings at 8 DAS. (The lower confidence limit for the 7 DAD machine sowing was −5% emergence, but is illustrated here only as far as the x-axis.)

not determined. Often, several seeds were delivered together followed by a gap with no seed, but gaps were generally <20 cm. The major benefits of the seeder were its ease and speed of use.

Comparison of field germination with predictions made from controlled-environment studies

In controlled-environment studies on the combined effects of constant temperature and water potential on mungbean seed germination (Fyfield and Gregory, 1989), two equations were derived. The first described the relationship between median germination time in days (Gt_{50}), osmotically created water potential (ψ_w) and temperature (T)

$$Gt_{50} = [15.5 - 24.2(\psi_w)]/(T - 10.1)$$

where $-1.7 \leqslant \psi_w \leqslant 0$ MPa and $10.1 < T \leqslant 40°C$. The second described the correlation between Gt_{50} and final percentage germination (G_f)

$$G_f = 112 - 38(Gt_{50}) + 9.5(Gt_{50})^2 - 0.9(Gt_{50})^3$$

These equations were used to predict median germination time and final percentage germination from soil matric potential (assuming $\psi_m \equiv \psi_w$) and daily mean temperature recorded at 5-cm depth for each sowing in the field experiments. An approximate Gt_{50} was calculated based on ψ_m and T values recorded on the day of sowing, then the predictions made using values averaged over the required time period in order to allow for soil drying. Figure 7 shows the relationship between predicted and observed germination percentages. In the earlier sowings (2–8 DAD), where the soil was still quite moist ($\psi_m > -0.1$ MPa), observed percentages were all slightly higher than those predicted. However, at the three later sowings (13 DAD in Experiment A, and 10 and 14 DAD in Experiment B), where the soil had dried to < -0.7 MPa, observed percentages were considerably lower than those predicted. This result is similar to that found by Fyfield and Gregory (1989) in soil columns and again indicates the probable importance of seed/soil/water contact. In the previous study (Fyfield and Gregory, 1989) mungbean seeds made contact with osmotic solutions at various water potentials through semi-permeable membranes. In the field, however, better all-round contact probably occurred in moist soil, thus enhancing germination, whilst in drier soils the rapid depletion of soil water immediately adjacent to the seed, and the comparatively low hydraulic conductivity of soil, may have resulted in a lower potential than

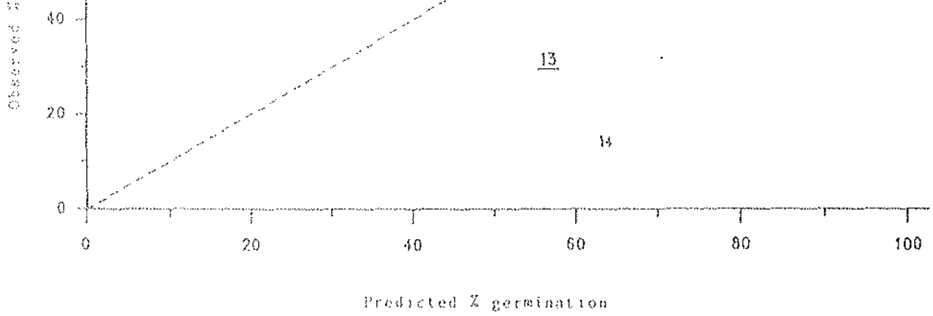

Fig. 7. The relationship between predicted and observed final germination percentages obtained after manual sowings in Experiments A and B. Points are the time of sowing (DAD) with tilled treatments underlined. The dashed line is the 1 : 1 relationship.

that experienced with the well-circulated osmotic solutions, thus inhibiting germination to a greater extent than expected.

CONCLUSIONS

These results indicate that following drainage of a previously puddled soil, the manual sowing of mungbean (c.v. IPB-M79-17-79) at a depth of 5 cm could be delayed until 8 DAD (i.e. while soil matric potential remained > -0.1 MPa) without a significant decrease in seed germination. In non-tilled soil, however, subsequent emergence was, in some cases, severely inhibited by the drying, hardening seedbed. A lessening of seedbed strength, either by cultivation prior to sowing in Experiment A or disturbance of the soil surface before drainage in Experiment B, resulted in increased emergence and faster seedling growth. After 8 DAD, both germination and emergence were reduced because the soil then became too dry. With the seeding machine and its constraint of shallow sowing depth, a shorter sowing delay was possible (only to 5 DAD) before establishment was inhibited. Predictions of percentage germination were made using equations derived from controlled-environment studies and differences from observed germination could probably be accounted for by seed/soil/water contact effects. In these earlier studies (Fyfield and Gregory, 1989), mungbean seeds were found to germinate at osmotically determined water potentials as low as -2.2 MPa, whereas in dry soil a much greater restriction on germination is clear. Soaking seeds in water prior to seeding has been reported to compensate for inadequate seed/soil contact and improve crop establishment (I.R.R.I., 1988).

Whilst the seedbed condition in neither experiment is likely to reflect exactly that following a wetland rice crop, it is clear that some form of surface soil disturbance is desirable in order to allow optimum emergence and seedling growth of a subsequent mungbean crop. However, a drying pattern similar to that in Experiment B would mean that tillage per se prior to sowing such a crop may not be necessary. If following drainage the rice is to be harvested before a dryland crop is sown, the resulting delay may allow the soil to dry too much. Relay cropping would overcome this problem and a seeding machine, such as the prototype tested in Experiment B (after some modification to try and ensure a slightly deeper sowing depth), would be ideally suited for this purpose. Rice straw mulch, by conserving soil moisture and maintaining lower seed-zone strength, has also been shown to improve the emergence and early growth of post-rice mungbean (I.R.R.I., 1988).

The results reported here apply only to one soil; further studies should be conducted on more than one type in order to allow for potential differences in drying rate. Additional field experiments are also needed to test the effects of using shallower sowing depths and different sowing techniques (e.g. broadcasting). Care must be taken to ensure uniformity of seedbed treatments and drying rates prior to such experiments. These should preferably follow a rice crop instead of using simulated conditions, since only when the actual effect of a preceding rice crop on the drying pattern of the soil is known can the degree of cultivation required for a subsequent dryland crop be truly assessed.

ACKNOWLEDGEMENTS

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PAPER II

Effects of Tillage Systems and Seed Coulters on Seedbed Properties and Yield of Spring Barley

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Abstract

A factorial experiment on the effects of mouldboard ploughing to 25 cm depth versus stubble cultivation to 13 cm depth in autumn combined with 0, 1 and 3 harrowings and three seeders was carried out in one site in 1992. In an adjacent site, the same primary tillages combined with 3 passes of an S-tine harrow for seedbed preparation was compared with direct drilling using seeders as in site 1. In both trials, seedbed properties, emergence and yield of spring barley were determined. Emergence was more positively influenced by harrowing in the stubble-tilled compared to the ploughed soil in site 1. Grain yield after stubble cultivation was also higher although emergence was slightly lower than after ploughing. In site 2, more than 50 percent of aggregates > 5 mm in the whole seedbed resulted in lower emergence but not in lower yield. Among the coulters tested, the JB (a prototype seeder for reduced tillage) had the least emegence in both sites but had the greatest grain yield in the first and similar in the second. Significant reduction in plant emergence with direct drilling in site 2 resulted in a non-significant decrease in grain yield. Yield compensation led to improved yield per plant at low plant density.

Introduction

Primary tillage in autumn has been considered a good soil management in Scandinavian countries since the frost action during winter produces pronounced granular structure in the surface layer. The benefit is obtained by exposing the furrow slice to freezing. During freezing, ice bands grow at the expense of the water in the unfrozen soil, which itself contracts in three dimension, forming patterns of vertical and horizontal cracks dividing the soil into roughly cubic blocks (Payne, 1988).

During recent decades reduced tillage has been the focus in Swedish tillage research. Its aim is to improve soil properties as well as to reduce soil compaction and moisture loss during spring. Due to increasing prices of fuel and energy and the need to cut production cost, reduced tillage is being increasingly adopted by farmers. Studies in Sweden have often shown improved yields under reduced tillage. In an eight-year field trial with clayey soils, Comia et al. (1992) found that reduced tillage resulted in equal or greater yields of barley, oats and wheat as compared to mouldboard ploughing in 12 out of 18 occasions wherein 5 instances were statistically significant. Rydberg (1987) reported increased yield of oats, first year leys, and potato but a decrease in winter and spring oilseed rape, and sugar beet from reduced tillage.

Workers in other countries found similar or greater yields of maize (Smith and Yonts, 1988); cowpea (Gupta, 1987) and peanuts (Hartzog and Adams, 1985; Colvin et al., 1985) with minimum compared to conventional tillage. On the contrary, minimum tillage was found to reduce yields of spring barley (Barak, 1984; Kholmov et al., 1986) and maize and soybean (Camp et al., 1984).

Crop response to tillage systems varies in relation to weather and soil types. On poorly drained soil, Kladivko et al. (1986) found that conservation tillage generally yielded less maize grain than conventional ploughing due to low soil temperature and excessive wetness in spring. On the contrary, Toderi and Bonari (1986) found that minimal and zero tillage gave better yields than conventional in soils with high content of fine sand or silt but lower yield on clay soils with waterlogging. They also reported that reduced tillage gave better yields if rainfall was moderate or low. Other researchers (Weber et al., 1987; Ekeberg, 1987) reported that adverse effects of reduced tillage were usually associated with excessive soil wetness during growing season, while better yields were obtained with less than adequate rainfall or during very dry years.

From the above reports, reduced tillage seem to work best when there is a drying period and is thought to be partly attributed to the properties of the seedbed formed during cultivation and sowing. However, both seedbed preparation and sowing often pose difficulties during fast-drying soil conditions. Experimental results have shown that increased number of harrowing passes (Henriksson, 1989) and greater proportion of aggregates less than 5 mm in diameter (Vyn et al., 1979) increased the yield of spring-sown cereals.

This study describes the properties of the seedbed formed by conventional ploughing, stubble tillage and no-tillage in autumn in combination with various seedbed preparations and seed coulters in spring, and the response of spring barley. Mechanisms behind the responses are discussed.

Materials and Methods

Experimental sites and design

Two field experiments on clay soils (Table 1) were conducted in 1992 near Uppsala, Sweden. Both sites were stubble cultivated once before treatments were imposed.

In site 1, two primary tillages; conventional mouldboard ploughing to 25 cm depth and stubble cultivation (2 passes with spring tine cultivator) to 13 cm depth were done in the preceding autumn each in three plots per block. In the spring, three seedbed preparations, zero, one pass and three passes of an S-tine harrow, were imposed on both primary tillage treatments in each block to form the main plot. Because harrowing on a bigger area was more practical and primary tillage considered more important, primary tillage was assigned to subplots. Three seed coulters, (Nordsten, JB Special and Ekoodlaren, see description below) were assigned as sub-sub plots in a split-split plot design. The experiment used four blocks with sub-subplot size of 4 x 20 m.

In site 2, three main treatments; autumn mouldboard ploughing with conventional seedbed preparation, autumn stubble cultivation with conventional seedbed preparation and direct drilling were combined with the same seed coulters as in site 1 (except that Bettinson replaced Nordsten in direct drilling) in a split plot design with four blocks. The seedbed preparation was done by 3 passes of an S-tine harrow. Plot size was similar to site 1.

Ammonium sulfate at 78 kg N/ha were combi-drilled with the Nordsten and JB but broadcasted with the Ekoodlaren in the first site, and in all cases was broadcasted in the second. In both fields, about 400 seeds/m^2 of spring barley (*Hordeum vulgare* L.) were sown on 15 May 1992. Post-emergence herbicide was applied according to local recom-mended rate. Harvest was done on 7 September in site 1 and on 30 August in site 2.

Measurements

Seedbed properties

A steel frame, 1600 cm^2 by 10 cm height, with a side-wing 1000 cm^2 by 10 cm height (Kritz, 1983) was used to measure seedbed properties. Near the end of each plot between wheel tracks, the frame with the side-wing was pressed down into the soil by a mallet. Aggregate size distribution, seed placement and moisture content of the seedbed and seedbed bottom were measured from the side-wing. The seedbed was divided into 3 layers of approximately equal thickness by collecting approximately one third of the loose soil each time with the use of a 25-cm wide scoop. The soil from each layer was sieved in three aggregate size fractions: > 5, 2-5 and < 2 mm. Seeds found in each layer and in the seedbed bottom were counted to determine seed placement. Surface roughness was determined by measuring the highest and lowest points from the seedbed enclosed by the steel frame. The loose soil was then removed and the highest and lowest position were again measured for the bottom roughness. The depth of the seedbed was estimated by measuring the volume of the removed loose soil in a way that does not significantly change the bulk density (Kritz, 1983). Soil moisture content was determined gravimetrically from subsampled mixture of the soil in the three layers of the seedbed while another sample was taken from an approximately 2 cm deep layer below the loose seedbed. Soil moisture content is reported as a weighted average from the seedbed and seedbed bottom.

Weed density, crop emergence and grain yield

Weed density and crop emergence were determined at Zadoks stages 16-20 (Zadoks et al., 1974) by counting the number of plants within a 0.25 m^2 area from both ends of each plot. Grain yield was determined in all plots from a 28m^2 harvest area in the center of each plot and presented at 15% moisture content.

Moisture loss as measured by the time-domain reflectometry

The time-domain reflectometry (TDR) was used to monitor soil moisture loss (volumetric water content) during the first three weeks after seeding. Measurements were taken from the conventional ploughing under 0 and 3 harrowings with Nordsten in site 1. After removal of the loose seedbed from each plot a pair of 17 cm long probes or waveguides was pushed vertically to a depth of 10 cm and moisture content measured by a portable TDR unit, Tektronix 1502 TDR cable tester (Topp and Davis, 1981). In addition, steel cylinders 7.2 cm inner diameter and 10 cm high were used to sample duplicate soil cores from each plot mentioned above after removal of the loose seedbed layer. These cores were the oven-dried to calculate bulk density which in turn were used to convert the volumetric wetness (%) measured by TDR into mass wetness (%).

Others

The general linear model (GLM) procedure (SAS, 1985) was used to analyze the data. To simplify analysis for site 2, only two seed coulters; JB and Ekoodlaren were considered in direct drilling treatment.

Daily precipitation and evapotranspiration were obtained from Uppsala Meteorological Station, several kms from the experimental site.

Description of the seed coulters

The Nordsten is a conventional combi-drill consisting of a frame, seed box, seed hopper, share coulters and side-mounted wheels. The share coulters were mounted on a front and a rear rack. The coulter ties were individually joint to one shaft. Attached to the seed hopper are the coulter springs, and lifting of the coulters is done by elevating the entire hopper. The working depth was controlled by the interaction between the soil resistance and spring pressure on the coulter. One row of fertilizer coulters was mounted in front of the seed coulters and place fertilizer in the centre of every second interrow. Crop row spacing is 12.5 cm.

The JB is a prototype drill designed for reduced tillage but also for use after conventional tillage and as a direct drill. It has wheels, seed box, frame and seed hopper with distribution rolls taken unaltered from a Tive air drill. Another frame with the coulters is mounted on the rear of the implement. The drill coulters, in 2 rows, consisted of 13 cm wide duckfoot shovels placed 25 cm apart. Every coulter seeds two bands of 12.5 cm row distance. The coulter also deliver fertilizer from its center and places it 1 cm deeper than the seeds. A disc acting as an opener precedes each seed coulter and a presswheel acting also as a depth control follows thereafter. Drilling depth is regulated by a spring pressing down the coulter and the link from the depth control wheel limits the working depth. It may, if necessary, be equipped with a levelling board.

The "Ekoodlaren" is a new implement constructed to prepare the seedbed, fertilize, and row weed in single or combined operations after conventional, reduced or zero tillage. It consists of a frame, a seed box, wheels, duckfoot shovels and seed hopper. The hopper with distributor rolls and fan emanate from a Tive air drill. The coulters are 40-cm wide duckfoot shovels each mounted on one bogie. Seeding is carried out as twin bands at 16 cm between the centres of the bands with 20 cm between any two double bands. The bogie mounted wheels act as presswheels and control the working depth.

Figure 1 shows diagram of the conventional seed coulter (Nordsten) and the prototype drills (JB Special and Ekoodlaren).

Results and Discussion

Weather in Uppsala during spring 1992

Monthly precipitation and potential evaporation in Uppsala for 1992 and means for a 30-year period are shown in Table 2. The precipitation in May and June was lower while evapotranspiration higher than the 30-year average. Both precipitation and potential evaporation in July were higher than the long-term mean. Both parameters were similar to the long-term mean in August but lower in September. Although the weather during the course of this experiment was relatively dry as compared to the long-term mean there were some days with rain before sowing (Fig 2).

From experimental site 1

The size distribution of the aggregates was not significantly different among harrowings in any of the three seedbed layers (Table 3) but there was a tendency to increase the amount of coarse aggregates in layer 1 after harrowing, whereas the reverse in the deeper layer was probably a sorting effect of the harrow on this soil that has a very stable structure. With stubble cultivation the proportion of aggregates > 5mm in the topmost layer of the seedbed was significantly higher than with conventional tillage. Conversely, the proportion of 2-5 and < 2 mm aggregates was significantly lower. In layers 2 and 3 there were no significant differences in the amount of the > 5 and < 2 mm sizes between tillage. However, the fraction of 2-5 mm was significantly lower with stubble cultivation. The aggregate size distribution in layer 1 was not significantly different among seeders but in layers 2 and 3 the proportion of these < 2 mm was significantly higher with Nordsten.

Neither tillage nor harrowing influenced seed placement significantly in the seedbed layers (Table 4). On the other hand, the JB placed significantly higher proportion of seeds in layer 1 and these seeds could mainly be losses from the seed hopper transported with turbulent air flow. Seeds at this layer did not emerge probably due to fast evaporation resulting in limited moisture at the surface layer.

Surface and bottom roughness were not significantly different between autumn tillages. With 3 harrowings the surface roughness was significantly lower than with 0 and 1 (Table 5). Of the three coulters, the Ekoodlaren created a deeper seedbed with rougher surface. This coulter was not equipped with presswheels to recompact and level the seedbed after sowing. Additionally, although a shallow seeding (4 cm) was set for this machine a much deeper (5.2 cm) seedbed was attained. Because moisture increases with depth and the sampling position for moisture content is relative to the depth of the loose seedbed, higher moisture content was found in the seedbed and at approximately 2 cm layer below the seedbed bottom. This indicates that for field operations, intended characteristics influenced by the settings like working depth by big machines are sometimes hard to attain.

Percent emergence was significantly higher with 1 and 3 harrowings than with 0 (Table 6). Although average water content in the seedbed and seedbed bottom at seeding meets the requirement for good germination specified by Håkansson and von Polgár (1984); viz that 5 g of plant available water $100g^{-1}$, higher evaporation rate with no harrowing could have caused the difference in percent emergence. The data in Table 3 indicated that harrowing may have sorted the bigger aggregates to the surface and the smaller ones closer to the seed (Henriksson (1989), a favorable condition minimizing evaporation loss. Henriksson (1989) also suggested that on a clay soil a uniform seedbed could minimize evaporation during germination and this condition was also attained in this trial under 3 harrowings (Table 5). Three harrowings reduced moisture loss compared to 0 pass as measured by the TDR (Fig 3). The higher proportion of aggregates > 5 mm in the stubble tillage did not significantly affect percent emergence. Lowest plant density was observed with JB, intermediate with Ekoodlaren and greatest with Nordsten. By contrast, significantly higher grain yield was obtained with the JB (Table 6). Harrowing once or thrice increased grain yield while stubble cultivation yielded higher grain than mouldboard ploughing.

Weed population was generally low and unimportant in this experiment although it was higher in stubble-tilled than in ploughed plots.

The finding that higher grain yield from the use of JB though lower in emergence than other coulter as well as higher grain yield from stubble tillage with similar emergence compared to ploughing somehow relate with those obtained by Christian and Bacon (1990). They found that there was a compensatory plant growth often adjusting for low population in spring-sown cereals such that a significant difference between plant populations, did not vary shoot number significantly. In one year of their experiment, significantly fewer fertile ears did not result in lower yield. However, they cannot explain it by difference in thousand grain weight. In the present study the difference in grain yield was not also reflected in the thousand grain weight (data not shown). Singh et al. (1985) suggested that yield compensation could be achieved from higher fertility of the side tillers and from a large number of grain per ear. Similarly, Pollard et al. (1981) found that smaller number of plant produced larger grain and greater number of ears at harvest. They suggested that the high number of plants on the ploughed plots could not be supported to harvest and the ability of the remaining tillers to produce grain could be reduced by the intra-crop competition.

The compensatory plant responses maybe partly related to soil properties beneath the seedbed. In similar soils, Comia et al. (1992) found that with the same stubble cultivation as the one used here there was a higher volume of pores 5-30 µm in the 13-18 cm layer and of > 100 µm in the 25-30 cm layer compared with mouldboard ploughed soil. A minimal disruption below the tilled layer (13 cm) in stubble system indicated a higher pore continuity index implying a more continuous soil pore system as compared to the ploughed. In another report, shallow cultivation produced most roots with greater proportion of root system below 20 cm compared with direct drilling and mouldboard ploughing (Chaney et al., 1985).

A significant primary tillage x harrowing interaction ($P < 0.05$) was observed for plant emergence (Table 7). Under stubble cultivation harrowing increased emergence much more than under ploughed.

Tillage x coulter interaction was significant ($P < 0.05$) for grain yield (Table 8). The JB yielded highest among the 3 coulters. All of them yielded higher after stubble cultivation than after ploughing, but the difference between tillage treatments being greater for Nordsten than for the other.

From experimental site 2

The proportion of aggregates > 5 mm was significantly highest in the direct-drilled plots and lowest in the conventionally tilled soil in all layers of the seedbed (Table 9). There was no significant difference in aggregate size distribution as affected by various coulters.

There were no significant differences in percent seed distribution in various layers (Table 10), soil moisture content, seedbed depth or surface roughness neither between tillage nor coulter treatment (Table 11). Direct drilling as well as the use of JB resulted in significantly rougher seedbed bottom (Table 11).

The presence of more than 50 percent (66%) of aggregates > 5 mm in the direct-drilled plots adversely affected plant emergence. This did not conform to conditions suggested by Håkansson and von Polgar (1984) that for good seed establishment the seedbed should mainly consist of < 4 mm aggregates. The presence of big aggregates was found by Johnson and Buchele (1961) to increase soil drying rate and these big clods could have provided high mechanical impedance to the emerging shoot (North, 1987). Braunack and Dexter (1988) reported that increased aggregate size in drier year decreased both total dry matter and grain yield. However, grain yield was not significantly different in this trial.

Both weed population and crop emergence were significantly lower in the direct drilled plots (Table 12). However, a 44% reduction in plant emergence did not significantly reduce grain yield. This suggest that compensatory response either by increased tillering or bigger ears per plant by barley crop at low density could be a probable reason.

Indeed crop response to tillage and subsequent changes in soil properties is very complex. Non-capability to carry out sufficiently comprehensive field measurements in the very heterogeneous seedbed before the conditions have changed pose a big constraint to fully understand the mechanisms behind such soil-tillage-crop relationships.

Conclusions

* Harrowing beneficially influenced plant emergence more in the stubble tillage than in the mouldboard ploughing.
* Least plant density from the JB seed coulter in both sites produced highest grain yield in site 1 and similar in site 2.
* During spring with slightly drier weather than average the occurrence of high proportion (> 50 percent) of aggregates > 5 mm in the seedbed as in direct drilling adversely affected plant emergence.
* Greater plant density does not necessarily increase grain yield particularly in drier weather.
* Stubble cultivation in autumn in combination with harrowing in spring could be a better soil management alternative for barley production on a clay soil. Benefits could include higher grain yield with similar emergence compared to ploughed, possible savings in labor and energy and improved soil structure.

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Table 1. Particle size distribution and organic matter content of the topsoil in site 1, Uppsala, 1992

Site	Particle size (μm)				Organic matter ($g\ 100g^{-1}$)
	< 2	2-20	20-200	200-2000	
Site 1	56	29	14	1	6.5
Site 2	42	31	26	1	4.7

Table 2. Precipitation and evapotranspiration during spring at Uppsala, 1992

Month	Precipitation (mm)		Potential evaporation (mm)	
	1992	Monthly mean[1]	1992	Monthly mean[1]
May	21.5	32.8	105.6	89
June	22.1	45.9	128.8	103
July	117.4	70.5	106.1	97
August	67.7	66.4	69.8	70
September	46.5	57.0	30.1	34

[1] 1961-1990

Table 3. Aggregate size distribution (%) in three layers of the seedbed in site 1, Uppsala, 1992

	Layer 1			Layer 2			Layer 3		
	>5mm	2-5mm	<2mm	>5mm	2-5mm	<2mm	>5mm	2-5mm	<2mm
Tillage									
Conv	53b	23a	24a	33	31a	36	25	32a	43
Stub	71a	15b	14b	42	26b	32	26	28b	46
L.S.	**	**	*	ns	*	ns	ns	*	ns
Harrowing passes									
0	56	22a	22	40	27	33	28	30	42
1	66	17b	16	38	27	35	27	28	45
3	64	18b	19	34	32	35	22	32	46
L.S	ns	*	ns	ns	ns	ns	ns	ns	ns
Coulters									
Nord	57	20	23	32	29	39a	21b	30	50a
JB	64	19	17	41	28	31b	26ab	31	43b
Eko	65	18	17	39	29	32b	30a	30	40b
L.S.	ns	ns	ns	ns	ns	*	*	ns	**

L.S. (Level of Significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$, *** = $P \leq 0.001$, ns = not significant

Table 4. Proportion of seeds placed in the three layers of the seedbed and in the seedbed bottom in site 1, Uppsala, 1992

	Layer 1	Layer 2	Layer 3	Bottom
Tillage				
Conv	1.1	3.2	11.5	84.2
Stub	2.0	4.3	18.0	74.9
L.S.	ns	ns	ns	ns
Harrowing passes				
0	1.7	4.4	12.8	81.0
1	0.9	2.9	13.9	82.2
3	2.0	3.8	18.8	75.4
L.S.	ns	ns	ns	ns
Coulters				
Nord	1.4b	2.4	11.1	86.0
JB	3.1a	6.4	14.9	75.6
Eko	0.2b	2.4	19.5	77.9
L.S.	*	ns	ns	ns

L.S. (Level of Significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$, *** = $P \leq 0.001$, ns = not significant

Table 5. Surface and bottom roughness, depth, and water content of the seedbed in site 1, Uppsala, 1992

	Surface roughness (mm)	Bottom roughness (mm)	Seedbed depth (cm)	Water[a] content (g 100 g $^{-1}$)
Tillage				
Conv	53.4	23.6	4.3	25.15
Stub	54.9	34.5	4.3	23.88
L.S.	ns	ns	ns	ns
Harrowing passes				
0	58.4a	43.2a	4.2	23.39
1	57.6a	38.3a	4.7	25.02
3	46.5b	5.5b	4.0	25.90
L.S.	**	*	ns	ns
Coulters				
Nord	50.6b	20.8	3.8b	24.16b
JB	52.7b	39.2	3.9b	23.62b
Eko	59.2a	27.0	5.2a	25.77a
L.S.	*	ns	***	*

L.S. (Level of Significance): * = 0.05 ≥ P > 0.01, ** = 0.01 ≥ P > 0.001, *** = P ≤ 0.001, ns = not significant

[a]Soil moisture content at permanent wilting point = 22-23 % (w/w), estimated from an adjacent site with similar clay and organic matter content.

Table 6. Weed density, percent emergence and grain yield expressed at 15% moisture in site 1, Uppsala, 1992

	Weed density (plants/0.25 m^{-2})	Crop emergence (%)	Grain yield (kg ha^{-1})
Tillage			
Conv	1.3b	86.7	4799.9b
Stub	2.6a	82.8	5109.1a
L.S.	**	ns	**
Harrowing passes			
0	1.3	74.8b	4726.6b
1	1.9	88.8a	5036.3a
3	2.6	90.6a	5100.6a
L.S.	ns	**	*
Coulters			
Nord	2.17	93.2a	4912.9b
JB	1.81	77.4c	5116.9a
Eko	1.85	83.6b	4833.7b
L.S.	ns	***	***

L.S. (Level of Significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$, *** = $P \leq 0.001$, ns = not significant

Table 7. Tillage x harrowing interaction for percent plant emergence in site 1, Uppsala, 1992

Tillage	Harrowings			
	0 pass	1 pass	3 passes	Mean
Conventional	82.42	87.92	89.67	86.67
Stubble cultivation	67.17	89.58	91.50	82.75

Table 8. Tillage x coulter interaction for grain yield in site 1, Uppsala, 1992

	Tillage treatment		
Seed coulter	Conventional tillage	Stubble cultivation	Mean
Nordsten	4649.7	5176.1	4912.9
JB special	5012.8	5221.1	5116.9
Ekoodlaren	4737.3	4930.2	4833.7

Table 9. Percentage aggregate size distribution in three layers of the seedbed in site 2, Uppsala, 1992

	Aggregate size (mm)								
	Layer 1			Layer 2			Layer 3		
	> 5	2-5	< 2	> 5	2-5	< 2	> 5	2-5	< 2
Tillage									
Conv	34.4c	32.1a	33.5a	21.2b	31.1a	47.7a	13.7b	33.4	53.0a
Stub	45.9b	22.4b	31.7a	27.0b	27.2a	45.8a	17.2b	28.7	54.1a
DD	85.5a	8.4c	6.1b	71.2a	14.2b	14.6b	42.7a	27.9	29.4b
L.S.	***	**	**	***	*	**	***	ns	***
Coulter									
Nord	40.0	26.6	33.4	27.1	28.9	44.1	17.6	31.1	51.2
JB	54.8	21.2	24.0	36.7	24.5	38.8	21.6	31.0	47.4
Eko	55.8	21.2	23.0	40.9	24.0	35.0	26.0	28.9	45.2
L.S.	ns	ns	ns	ns	ns	ns	ns	ns	ns

L.S. (Level of Significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$, *** = $P \leq 0.001$, ns = not significant

Table 10. Proportion of seeds placed in the three layers of the seedbed and in the seedbed bottom in site 2, Uppsala, 1992

	Layer 1	Layer 2	Layer 3	Bottom
Tillage				
Conv	2.0	3.2	21.3	73.6
Stub	0.7	0.0	35.5	63.9
DD	6.1	10.7	28.4	54.8
L.S.	ns	ns	ns	ns
Coulter				
Nord	0.7	2.3	15.8	81.2
JB	4.1	4.4	27.3	64.2
Eko	2.1	4.4	37.8	55.7
L.S.	ns	ns	ns	ns

L.S. (Level of significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$,
*** = $P \leq 0.001$, ns = not significant

Table 11. Surface and bottom roughness, depth and soil moisture content in the seedbed and seedbed bottom in site 2, Uppsala, 1992

	Surface roughness (mm)	Bottom roughness (mm)	Seedbed depth (cm)	Water content[a] (g 100 g^{-1})
Tillage				
Conv	49.3	27.7b	4.88	19.7
Stub	52.5	22.4b	5.22	20.1
DD	61.4	41.4a	4.59	18.8
L.S.	ns	*	ns	ns
Coulter				
Nord	47.5	24.8b	5.06	20.8
JB	52.8	36.7a	4.42	18.6
Eko	58.2	24.5b	5.38	19.8
L.S.	ns	**	ns	ns

L.S. (Level of significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$,
*** = $P \leq 0.001$, ns = not significant

[a]Soil moisture content at permanent wilting point = 17-18 % (w/w), estimated from an adjacent site with similar clay and organic matter content.

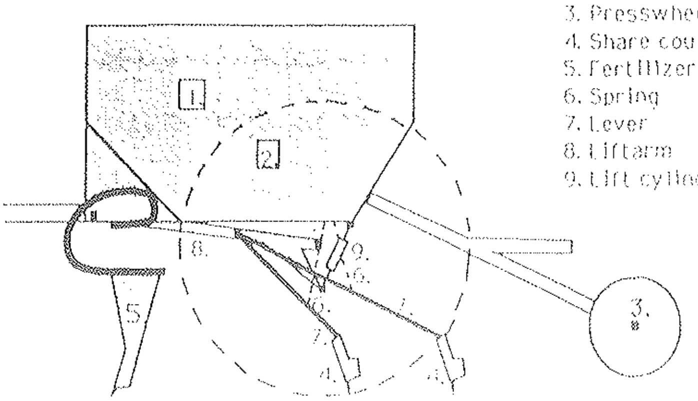
Table 12. Grain yield, crop emergence and weed density in site 2, Uppsala, 1992

Tillage	Weed density (plants 0.25 m^{-2})	Crop emergence (%)	Grain Yield (kg ha^{-1})
Conv	12.4a	92.5a	4536.4
Stub	8.6b	88.1a	4400.8
DD	1.4c	55.9b	3964.8
L.S.	**	*	ns
Coulter			
Nord	9.2	95.5a	4628.1
JB	8.0	71.6c	4391.9
Eko	7.8	82.6b	4154.5
L.S.	ns	*	ns

L.S. (Level of significance): * = $0.05 \geq P > 0.01$, ** = $0.01 \geq P > 0.001$, *** = $P \leq 0.001$, ns = not significant

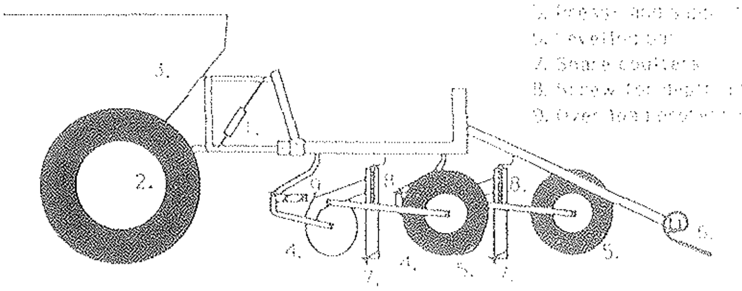
(a)

1. Seed hopper
2. Landwheel
3. Presswheel
4. Share coulter
5. Fertilizer coulter
6. Spring
7. Lever
8. Liftarm
9. Lift cylinder



(b)

1. Hydraulic cylinder
2. Landwheel
3. Seed hopper
4. Disc coulter
5. [illegible]
6. [illegible]
7. Share coulters
8. Screw for depth adjustment
9. [illegible]



(c)

1. Frame
2. Hydraulic cylinder
3. Share coulters
4. wheels
5. Bogie mount
6. Link frame-bogie
7. Cage roller
8. Scrubber
⊠ Joint

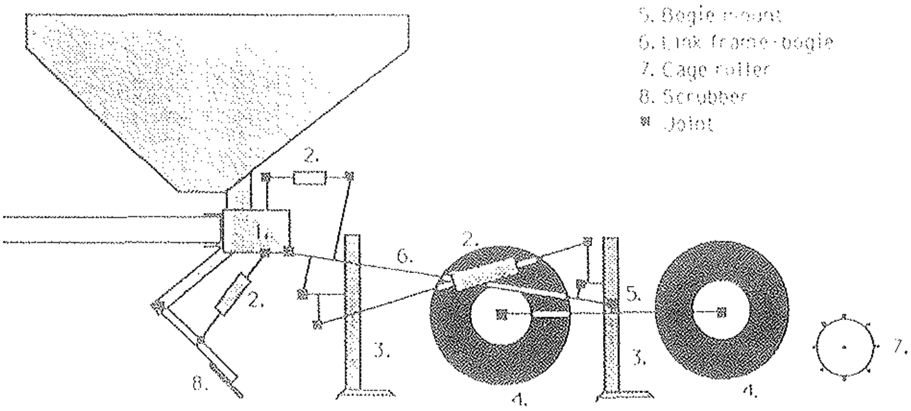
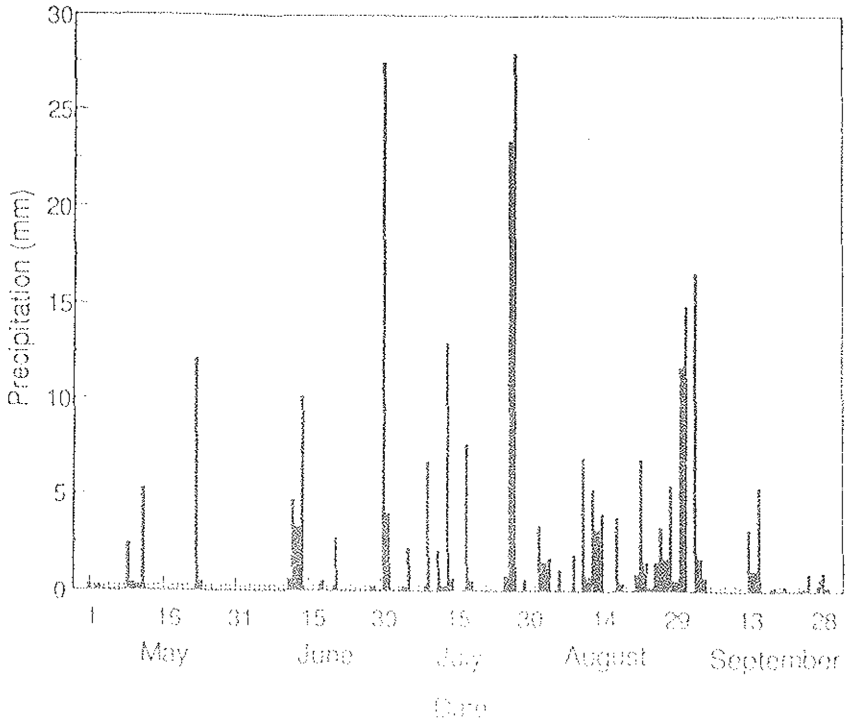
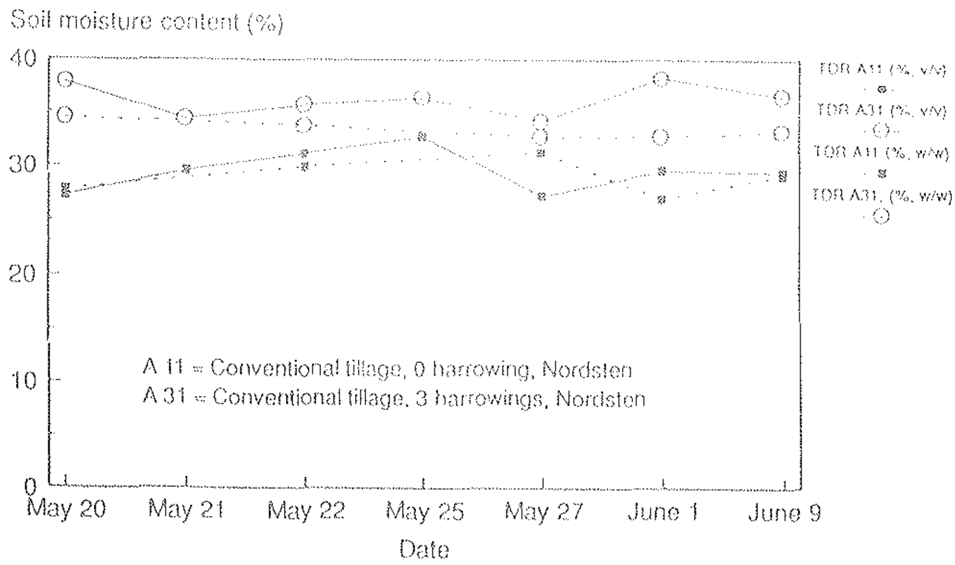


Fig. 1



30
25
20
15
10
5
0
Precipitation (mm)
1
15
31
15
30
15
30
14
29
13
28
May
June
July
August
September
Date

Fig. 2



Soil moisture content (%)
40
30
20
10
0
TDR A11 (%, v/v)
TDR A31 (%, v/v)
TDR A11 (%, w/w)
TDR A31, (%, w/w)
A 11 = Conventional tillage, 0 harrowing, Nordsten
A 31 = Conventional tillage, 3 harrowings, Nordsten
May 20
May 21
May 22
May 25
May 27
June 1
June 9
Date

Fig. 3

PAPER III

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GROWTH OF SOYABEAN (*GLYCINE MAX*) AND MUNGBEAN (*VIGNA RADIATA*) IN THE POST-MONSOON SEASON AFTER UPLAND RICE

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SUMMARY

Shoot and root growth and soil water depletion were studied in mungbean and soyabean grown at three plant populations after non-flooded rice (*Oryza sativa*) during the post-monsoon dry season in the Philippines. The site had a shallow fluctuating water table (1–2 m) but rooting depth was restricted to 0.8 m by a volcanic tuff layer. Soyabean had a longer duration (89 days) than mungbean (68 days) and intercepted more solar radiation, but from 61 days after sowing was severely stressed and accumulated little dry matter. Mungbean avoided severe water stress due to its short duration. Despite this stress, grain yield (1.0 t ha^{-1}) was similar for the two species and soyabean yielded more grain nitrogen but less straw nitrogen than mungbean. Higher plant population achieved by narrower row spacing increased cumulative light interception and both grain and forage yields in both crops.

K. D. Shepherd, P. J. Gregory, T. Woodhead, R. K. Pandey y E. C. Magbujos: *Crecimiento de la soja* (Glycine max) *y del frijol mungo* (Vigna radiata) *en la estación post-monzón después del arroz de secano.*

RESUMEN

El crecimiento del retoño y la raíz y la reducción del agua fueron estudiados en el frijol mungo y la soja cultivados en tres densidades de plantación después de arroz no-inundado (*Oryza sativa*) durante la estación seca post-monzón en las Filipinas. La localidad contaba con una capa freática fluctuante de poca profundidad (1–2 m), pero la profundidad de las raíces quedaba limitada a 0,8 m debido a una capa de toba volcánica. La soja tuvo mayor duración (89 días) que el frijol mungo (68 días), e interceptó una mayor cantidad de radiación solar, pero a partir de los 61 días después de la siembra sufrió gran estrés y acumuló muy poca materia seca. El frijol mungo evitó un severo estrés por falta de agua debido a su corta duración. A pesar de este estrés, el rendimiento de grano (1,0 t $há^{-1}$) fue similar para ambas especies y la soja rindió más nitrógeno en grano pero menos nitrógeno en paja que el frijol mungo. Una mayor densidad de plantación, lograda mediante un espaciamiento de hileras más estrecho, aumentó la intercepción cumulativa de la luz y los rendimientos tanto de grano como de forraje en ambos cultivos.

INTRODUCTION

Food production in many rainfed, rice-growing areas of south and southeast Asia could be increased through greater production of dryland crops grown after rice during the post-monsoon, dry season. The productivity of these crops depends largely on successful crop establishment and the availability of soil water (Zandstra, 1982).

For maximum grain yield, the rate and duration of crop growth need to be matched to the water supply (Monteith, 1986). If early growth rates are too fast or the duration of vegetative growth too long, there may be insufficient water for reproductive growth and consequently a low harvest index and a reduced grain yield. Conversely, if vegetative growth is too little, the available water supply may not be fully utilized and grain yield below maximum.

The amount of water potentially available to dryland crops depends on both the amount of water stored and additions from rainfall or upward movement of water from a shallow water table. Several studies have shown that dryland crops grown after rice can extract substantial amounts of stored soil water (e.g. Angus *et al.*, 1983; Klodpeng and Morris, 1984).

Solving the soil water balance equation to give the water extraction by root systems is difficult in layered or heterogeneous soils or where a shallow water table persists. Such conditions are common in soils where rice is grown and patterns of hydraulic potential with depth may be complex (Klodpeng and Morris, 1984). The persistence of a water table after rice has been harvested and its effects on the soil water balance have rarely been examined for crops grown in the post-monsoon season.

Previous work has shown that yields of mungbean grown after upland and lowland rice are related to rooting depth and the amount of intercepted solar radiation (IRRI, 1986a) and has raised questions about the optimum growth duration and plant population for these conditions. The present study describes the growth of dryland crops (soyabean and mungbean) following non-flooded rice. The objectives were to examine the effects of (a) crop duration and (b) plant population on the interception of solar radiation and the accumulation and partitioning of crop dry matter and nitrogen, and to describe patterns of soil water movement during the growth of dryland crops so that appropriate methods for measuring soil water balances could be developed.

MATERIALS AND METHODS

The experimental site, located at the International Rice Research Institute in the Philippines (14° 11′ N, 121° 15′ E, 23 m elevation), was gently sloping (1.5%) with a perched water table caused by flood irrigation of rice in adjacent areas. The soil, a fine, mixed, isohyperthermic Typic Hapludoll, had a silty clay topsoil (0–0.25 m) over a subsoil of clay interspersed with fragments (0.4 to 5 cm) of tuffaceous materials which extended to 0.7–0.9 m depth. Below this was compact, horizontally-stratified, volcanic tuff to beyond 2 m. The topsoil was rotovated several times to a depth of 15 cm prior to sowing legumes on 9 January 1986; the preceding crop during the 1985 wet season was non-flooded rice (IR36 and UPLRi-5).

The two species, mungbean (CES-1d-21, a 65-day determinate type) and soyabean (SJ2, a 105-day determinate type), were grown at three row spacings (0.25, 0.50, and 0.75 m) in a factorial design with three blocks. Each plot was

14 rows wide and 12 m long. The soyabean seed was inoculated with rhizobium immediately before sowing, but this was unnecessary for mungbean. Plots were irrigated with 20 mm water immediately after sowing to ensure seedling establishment and the plants thinned at 11 days after sowing (das) to give a spacing of about 10 cm between plants within rows. No fertilizer was applied, and weeds and pests were controlled. Mungbean was harvested on 18 March 1986, and soyabean on 8 April 1986.

Crop development stages were scored at least twice weekly using the system of Fehr and Caviness (1977). Shoots from 1 m lengths of two adjacent rows were sampled at ground level six or seven times during growth, but at maturity 2 m samples were taken from two adjacent rows; any fallen plant material was also collected from the sample area. Dry weights of laminae, stems and petioles, and pods were determined by oven-drying at 80°C, and laminae areas were measured using a planimeter. Concentrations of N, P and K in the total shoot were determined on sub-samples from narrow and wide rows on three sample occasions. At harvest, additional 4 m samples were taken from six adjacent rows for grain yield, forage yield (standing dry matter after the pods had been picked) and yield components. The forage yield excluded fallen plant material. Mungbean was harvested in two pickings: the first picking was taken when 50% of the pods had matured and the second when 90% of the remaining pods had matured.

Radiation interception was measured throughout growth using tube solarimeters placed above and below the canopies, on two replicates of three treatments: soyabean in narrow (0.25 m) and wide (0.75 m) rows and mungbean in narrow rows. One solarimeter tube (0.9 m long) was placed across the rows in plots with narrow rows, but two tubes placed end to end were used in plots with wide rows.

Roots of both species were sampled at 25, 39 and 60 das from plots with narrow rows. Two cores (each 4.4 cm in diameter and 10 cm high) were taken at the position of the seed, plus two cores between plants within rows. The four cores were combined and washed over a 1 mm mesh screen and root length estimated from a projected photographic negative using the line intersect method (Tennant, 1975).

Soil water content was measured using a neutron moisture meter (Campbell Nuclear Pacific Corp.), from 0.20 to 1.45 m depth, beneath both species in narrow rows and soyabeans in wide rows. In plots with narrow rows, only one access tube was installed per plot (on the row) but in plots with wide rows, the tubes were positioned on the row, and at one quarter and half the distance between rows. Soil water content in the 0–0.2 m layer was estimated from four 4.4 cm diameter cores per plot.

Soil hydraulic potential was measured from 0.15 to 1.45 m depth adjacent to the neutron meter access tubes using one set of mercury tensiometers per plot. Occasional measurements of stomatal conductance were made using a porometer.

RESULTS AND DISCUSSION

Rainfall (53 mm) was near average (69 mm) from January to March 1986, with only one rain event greater than 5 mm occurring during the experiment (25 mm at 25 das). Irradiance was lower but wind speeds higher than the long-term averages so that potential Penman evaporation rates were near average (3.2 mm d^{-1}). Both irradiance and evaporation increased during the experiment, with potential evaporation rates of 5–6 mm d^{-1} on some days after 60 das.

Effect of species

Both species emerged at 4 das and began reproductive development at about 35 das. Full maturity was reached at 68 das in mungbean and 89 das in soyabean. Soyabean matured about two weeks earlier than expected.

Leaf area index (LAI) reached a maximum during early grain filling in both species (Fig. 1) and thereafter decreased to zero in soyabean but by only 17% in mungbean. Maximum LAI was 1.7 times greater in soyabean than mungbean. The extinction coefficient was calculated for each sample date until the start of rapid leaf senescence and was used to calculate the absorption of photosynthetically active radiation (PAR), after Gallagher and Biscoe (1978). PAR was assumed to be 0.55 of the total solar radiation (IRRI, 1986b). The values for the extinction coefficient for soyabean (0.51) and mungbean (0.67) compare with the range 0.34 to 0.50 determined at solar noon by Muchow (1985a) for legume crops grown on stored soil water. The amount of PAR absorbed from emergence to 61 das (the time of maximum dry matter accumulation in soyabean) was similar for both species because although mungbean had a lower LAI the extinction coefficient was greater (Table 1). However, using the same

Table 1. *Absorbed photosynthetically active radiation (PAR) and conversion efficiency of PAR into shoot dry matter from emergence to 61 das and crop maturity*

	Emergence–61 das		Emergence–maturity†	
Row spacing (m)	PAR absorbed (MJ m^{-2})	Efficiency of conversion (g MJ^{-1})	PAR absorbed (MJ m^{-2})	Efficiency of conversion (g MJ^{-1})
		Soyabean		
0.25	192	1.40	341	0.70
0.50	163	1.44	289	0.95
0.75	124	1.31	229	0.87
		Mungbean		
0.25	197	1.52	250	1.64
0.50	154	1.67	185	1.37
0.75	112	1.73	145	1.47
SED (any two means)	12	0.18	23	0.14

† 68 das for mungbean; 89 das for soyabean.

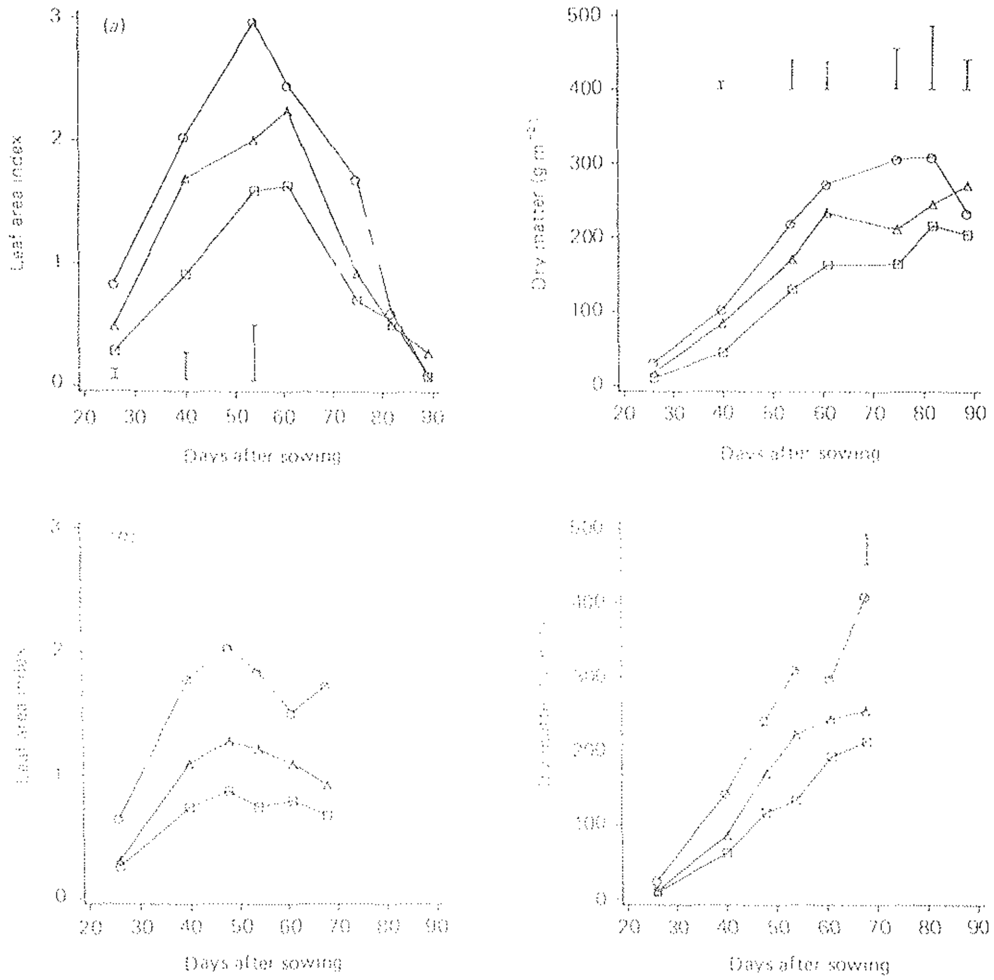

Fig. 1. Leaf area index and shoot dry matter accumulation in (a) soyabean and (b) mungbean at 0.25 m (○), 0.50 m (△) and 0.75 m (□) row spacings. Bars show the standard error of the difference for comparing any two species X row spacing mean values.

extinction coefficient for the whole season, soyabean absorbed more PAR than mungbean because of its longer canopy duration. Crop growth rates during the approximately linear phase of growth (26–61 das for soyabean and 26–68 das for mungbean) were not statistically different between species, but mungbean accumulated dry matter until maturity whereas soyabean accumulated little dry matter between 61 das and maturity (Fig. 1).

The efficiencies of conversion of absorbed PAR into shoot dry matter from emergence to 61 das (1.4 g MJ^{-1} in soyabean and 1.6 g MJ^{-1} in mungbean) compare with 1.3 and 1.9 g MJ^{-1} for soyabean (Muchow, 1985b; Muchow and Charles-Edwards, 1982, respectively) and 1.6 g MJ^{-1} for mungbean (Muchow, 1985b). The seasonal average conversion efficiency for soyabean (0.84 g MJ^{-1}) was about half that from sowing to 61 das because there was little dry matter accumulation between 61 das and maturity, but despite the slow rate of dry

Table 2. *Yield components*

Row spacing (m)	Number of plants (m^{-2})	Grain yield ($t\ ha^{-1}$)	Forage yield ($t\ ha^{-1}$)	Mean grain mass (mg)	Number of pods $plant^{-1}$ †	Number of grains pod^{-1} †
			Soyabean			
0.25	0.58	1.07	0.69	108	8.9	1.8
0.50	0.31	1.24	0.63	118	19.8	1.7
0.75	0.23	0.84	0.36	119	18.4	1.7
SED	0.01	0.09	0.03	4	2.6	0.1
			Mungbean			
0.25	0.64	1.32	1.88	58	5.4	7.5
0.50	0.31	0.84	0.99	57	7.9	6.2
0.75	0.22	0.92	0.97	59	8.6	8.2
SED	0.04	0.14	0.14	1	0.8	1.9

† One missing observation for soyabean at 0.25 m row spacing; SED is not adjusted.

matter accumulation during the latter half of reproductive growth in soyabean, grain yield was similar for both species (Table 2).

Pod mass was derived principally from current assimilate in mungbean but in soyabean a large proportion of pod mass was apparently translocated assimilate from leaves and stems; the maximum possible contribution of stored assimilate to final pod mass, estimated as the change in leaf plus stem mass between the full seed stage (R6, Fehr and Caviness, 1977) and maturity, was 54 ± 9% in soyabean and 15 ± 8% in mungbean. Because of the greater translocation of assimilate from leaves and stems to pods and the greater loss of senesced leaves and petioles, the forage yield of soyabean was generally less than half that of mungbean (Table 2) and there was a higher proportion of shoot dry matter in pods at maturity in soyabean (0.76) than in mungbean (0.60).

Although grain yields were similar for the two species, the grain nitrogen yield of soyabean (57 kg ha^{-1}) was 1.3 times that of mungbean (44 kg ha^{-1}); more nitrogen was apparently translocated from vegetative tissues to the grain in soyabean than in mungbean (total shoot nitrogen content was 1.4 times higher in mungbean than soyabean). However, the seasonal average daily rate of accumulation of grain N was the same for both species: 0.64 kg ha^{-1} d^{-1} for soyabean and 0.65 kg ha^{-1} d^{-1} for mungbean. The seasonal average daily rate of accumulation of total shoot N was substantially lower in soyabean (0.67 kg ha^{-1} d^{-1}) than in mungbean (1.19 kg ha^{-1} d^{-1}) because soyabean accumulated little nitrogen from 61 das. Shoot concentrations of N, P and K generally were similar between species and sample occasions (average values were 2.7 ± 0.1% N, 0.25 ± 0.01% P, and 2.1 ± 0.1% K) and both species had well nodulated root systems. These concentrations suggest that water stress, rather than nutrient stress, limited further growth of soyabean. This was confirmed by measurements of stomatal conductance (0.053 ± 0.007 cm s^{-1}) made between

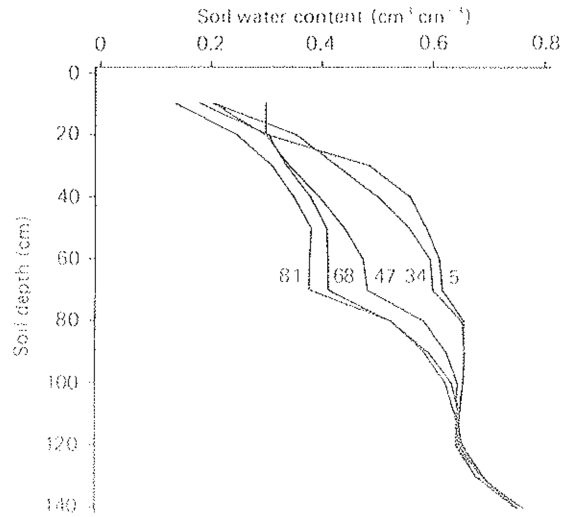

Fig. 2. Volumetric soil water content (averaged over species and row spacings) at 5, 34, 47, 68 and 81 das.

0800 and 1000 hours at 71 das and observation of wilting symptoms at mid-day from 55 das and at 0800 hours from 71 das.

The depth of the water table varied between plots (time-averaged values ranged from 1.0 to 1.3 m) and with time (the maximum fluctuation was about ± 0.2 m) in response to the irrigation of adjacent flooded rice fields. While the level of free water in soil pits alongside plots fluctuated in the range 0.9–1.5 m, a wet/dry soil interface was observed in the B horizon at about 0.7 m, 10 cm above the tuff layer. Consequently, soil water content below 0.7 m remained high throughout the experiment (Fig. 2) and hydraulic potential gradients confirmed that upward flux persisted above 0.8 m depth from 47 das. Changes in soil water content between emergence (5 das) and crop maturity (68 or 81 das) did not differ significantly between species (coefficients of variation were about 20%). Soil water content increased little from 5 to 34 das and from 68 to 81 das; between 34 and 68 das it decreased simultaneously in all soil layers between 0.2 and 0.8 m. Thus, when water over most of the root zone had been depleted, soyabean was apparently unable to take up water from the lower part of its root zone (0.7–0.8 m) fast enough to continue growth, despite high soil water contents maintained there by the water table.

Root length densities differed with depth ($P < 0.001$) but not species; coefficients of variation were about 35%. The depth of the soil zone which contained 90% of the total root length increased at an average rate of 1.18 ± 0.05 cm d^{-1} between sowing and 60 das. In soil pits, dug at 50 das, roots were observed to have grown horizontally along the layer of compact tuff at about 0.8 m, so that rooting depth was restricted, although some roots had penetrated cracks in the tuff. The total root length of the crops (1.3 km m^{-2}) was at the lower end of the range reported for grain legume crops (1.3–7.0 km m^{-2}; Gregory, 1988) and the root length densities were correspondingly lower also; at 60 das root length density was 0.38 cm cm^{-3} in the 0–0.1 m layer but was nearly uniform at about 0.12 cm cm^{-3} between 0.1 and 0.8 m depths. Assuming a typical average inflow of 0.05 ml cm^{-1} root d^{-1} (reported by Allmaras *et al.*, 1975), although maximum values are 10 times greater, the root length density of 0.1 cm cm^{-3} at 0.7–0.8 m could take up only 0.5 mm d^{-1} of water (compared with a potential rate of transpiration of 5 mm d^{-1}). Restricted rooting depth, small root length density at depth, and possibly large root resistance, therefore appear to be major constraints to further growth.

Effect of row spacing

As row spacing decreased, leaf area index and interception of PAR increased (Fig. 1 and Table 1). Row spacing did not significantly affect the seasonal efficiency of conversion of absorbed PAR into shoot dry matter (Table 1). Consequently, crop growth rates during the linear phase of growth were greater ($P<0.01$) with narrower rows (7.9 g m^{-2} d^{-1}) than wide rows (4.8 g m^{-2} d^{-1}). Both grain and forage yields were greater at the narrow spacing (intermediate spacing gave inconsistent results) although pod mass at maturity, as a fraction of shoot dry mass, was about 10% lower in narrow compared with wide row spacing. The number of grains per pod and mean grain mass were unaffected by row spacing (Table 2). Grain yields of soyabean were greater at narrow spacing despite an inadequate water supply and low rates of dry matter accumulation during the latter half of reproductive growth: the maximum proportion of pod mass apparently derived from translocated assimilate was 1.8 times greater in narrow than wide row spacings. It is unlikely that the increased shoot mass with narrower rows would have occurred entirely at the expense of a decreased root mass, so that crops in narrower rows probably transpired more water.

CONCLUSIONS

The results demonstrate that crops grown on stored soil water may experience severe water stress during reproductive growth if their duration is too long. However, grain yield may not be reduced relative to a shorter duration crop if sufficient assimilate can be translocated from vegetative tissue to the grain to compensate for reduced photosynthesis during reproductive growth. With a good water supply, long duration crops will have greater yield potential, and therefore, with a variable seasonal water supply, medium to long duration crops could give better long-term average yields than short duration crops. The results also show that higher plant populations can result in heavier grain yields, even with severe water stress during reproductive growth, and confirm the need for good establishment for maximum yields of dryland crops grown after rice.

Yields of long duration crops in these environments could be further increased if the rates of water uptake from deeper soil layers could be improved.

This could be achieved by selection for greater root length densities and faster inflows at depth, as well as improved penetration of hard soil layers and deeper rooting. However, future studies on water uptake by dryland crops require an appropriate methodology for measuring the soil hydraulic properties in layered and heterogeneous soils.

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