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Growth and yield response of grain legumes to different soil management practices after rainfed lowland rice

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Abstract

Field experiments were conducted over a 3-year period (1992–1995) in Sulawesi, East Java and the Philippines to investigate the response of post-rice (*Oryza sativa* L.) soil managements on growth and yield of legumes after lowland rice under rainfed conditions. Grain legume yields ranged from complete crop loss due to excessive rainfall after sowing to a maximum of 1.08 Mg ha^{-1} for mungbean (*Vigna radiata* (L.) Wilzek), 1.33 Mg ha^{-1} for soybean (*Glycine max* L. Merr.) and 2.3 Mg ha^{-1} for peanut (*Aracis hypogaea* L.). The response and magnitude of the effects from different management systems on legumes were closely related to the climatic conditions prevailing during the crop establishment phase. Correct timing of legume sowing was seen as the most important factor determining successful moderate crop production, followed by the availability of subsoil water reserves. Tillage was considered a potential method to improve yields because sowing could be carried out later during the dry season when rainfall was more predictable. Tillage, provided it is carried out at suitable soil water contents, could probably partially overcome the adverse soil physical condition induced during the rice phase. Fertiliser application tended to increase food legume in wetter areas showing that residual fertiliser effects from the previous rice crop could be limiting. In drier areas, fertiliser application had little effect on grain legume yields. Mulch as a soil amendment tended to increase yields in drier areas due to its water conservation effect. In wetter areas mulching was not necessary and could even lead to yield reduction if conditions were too wet. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Grain legumes; Soil management; Root growth; Rice

1. Introduction

The adoption of legumes into rice-based cropping systems, offers opportunities to increase and sustain productivity and income of small rice farmers in South East Asia. Puddling the soil and flooding are the common management systems for growing lowland rice under both rainfed or irrigated conditions. For Indonesia, rainfed lowland rice covers a total area of 3 million ha and makes up approximately one third of the total lowland rice area (Huke, 1982). In the irrigated lowland areas, legumes (soybean (*Glycine max* L. Merr.), peanut (*Aracis hypogaea* L.) and

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mungbean (*Vigna radiata* (L.) Wilzek) are generally grown in rotation of rice–rice–legume or rice–legume–legume with two or more irrigations during the season (Sumarno et al., 1988). In the rainfed lowland rice systems, it is not uncommon that the land is left fallow during the dry season. However, legumes are occasionally grown as an opportunity crop with very little inputs and yields are therefore very low. Yields of 0.3–0.8 Mg ha^{-1} for soybeans and 0.5 Mg ha^{-1} for mungbean are common and are well below their potential yields (So and Woodhead, 1987). Experiments at IRRI (1985, 1986) have shown that dry season mungbean immediately following rice, if well established, can achieve grain yields of 2.0 Mg ha^{-1} without fertiliser or irrigation. Although legumes grown as secondary crop after rice are normally not fertilised in the Philippines, potential yield increases due to additional fertiliser application are possible if residual fertiliser from the rice phase is inadequate. Yield increases ranging from 42 to 140% were reported by Adisarwanto and Suhartina (1994) in experiments conducted in East Java, Indonesia.

In lowland areas, the growing conditions required for rice are entirely different from those required for dry season legumes. Rice is grown best under puddled, reduced and anaerobic soil conditions, whereas legumes require un-puddled, aerobic and oxidised soil conditions. The two conditions are associated with large differences in physical, chemical and biological properties of the soil. The puddled conditions of the soil are a major cause of the poor establishment and performance of secondary crops after rice (Syarifuddin, 1979; Sumarno et al., 1988).

A major constraint to the production of dry season upland crops after rice is crop establishment in poorly structured seedbeds. Immediately after wetland rice the soil is still very wet and sowing under these conditions is expected to result in waterlogging and inhibit emergence and root growth. As the puddled layer dries out, soil strength increases rapidly. Hence, crop establishment and root proliferation through the puddled and compacted layers becomes increasingly more difficult. Time of sowing is therefore crucial for successful dry season cropping following rice. The optimum window for sowing is generally rather narrow, and will be determined by the interaction between crop growth and the prevailing environmental conditions. Although tillage can potentially be used to improve soil physical conditions, it is expensive, time consuming and often wasteful in terms of residual moisture (Gomez and Zandstra, 1976; Zandstra, 1982). Zero tillage could therefore be beneficial (Syarifuddin, 1982). Other difficulties for post-rice dryland pulses include insect damage. Under unfavourable conditions, such as too wet, too dry or excessively high temperatures, seedlings become prone to damage by Empoasca leaf hopper and flea beetles (Bandong and Listinger, 1976). These constraints indicate that early sowing and minimum tillage systems appear to be more reliable than conventional tillage systems (Suyamto et al., 1989). In the case of peanuts on light textured soils (Adisarwanto, 1993) and soybean (Sumarno et al., 1988), intensive tillage is not considered necessary before sowing.

It is possible to use tillage, fertilisers, soil amendments and mulch to improve the management of the soil and widen the window of opportunity for sowing legumes. The objective of this study was to determine the effect of these management practices on the growth and yield of three food legume crops (mungbean, soybean and peanut) grown after rainfed lowland rice.

This paper reports on the results on the influence of post-rice soil management practises on growth and yield on legumes. It is part of project funded by the Australian Centre for International Agricultural Research (ACIAR) which is described in detail by So and Ringrose-Voase (2000, this issue).

2. Material and methods

2.1. Field experiment E2

Field experiments were conducted with legumes on rice-based cropping systems from March to early June in 1992, 1993 and 1994 at the experimental stations or farms in Indonesia at Jambegede and Ngale in East Java and Maros, Sulawesi and in the Philippines at San Ildefonso and Manaoag. Details of the soils and climates have been discussed by Schafer and Kirchhof (2000, this issue).

Treatments were laid out as a randomised incomplete block design with four replicates. The treatments consisted of an incomplete factorial combination of amendments (none: A0; gypsum: AG; organic matter mulch: AOM); cultivation (zero-till and dibble: C0;

Table 1
Treatments depicted as a randomised incomplete block design with four replicates[a]

T1	C0	A0	D1	No fertiliser (farmers' practice in Indonesia)
T2	C0	A0	D1	Adequate fertiliser
T3	C0	AG	D1	Adequate fertiliser
T4	C0	AOM	D1	Adequate fertiliser
T5	C0	A0	D0	Adequate fertiliser
T6	C0	A0	D2	Adequate fertiliser
T7	C1	A0	D1	Adequate fertilisers
T8	C1	A0	D2	Adequate fertiliser

[a] A0: none; AG: gypsum; AOM: organic matter mulch; C0: zero-till and dibble; C1: rotovator and dibble; D0: no delay; D1: 1 week delay; D2: 2 weeks delay.

rotovator and dibble: C1) and sowing delay (no delay: D0; 1 week delay: D1; 2 weeks delay: D2) as shown in Table 1.

Originally D0 was to be immediately after harvest, but the appropriate sowing of D0 was left to the judgement of the local managers. Although progressive drying and a reduction in soil water contents was anticipated to be associated with sowing delay from D0 to D2, such a sequence was not always achieved due to rainfall.

Mungbean was planted as the common crop on all sites, but soybean was also used at Ngale and peanut at Jambegede. The latter two legumes are the main secondary crops in those regions. Each plot was approximately 5 m×4 m. Plant spacing was 40 cm× 10 cm with two plants per hill (equivalent to a moderate plant density of 330,000 plants per hectare) except for mungbean at Ngale and Jambegede where it was 30 cm×20 cm in 1993 and 1994. Sowing was conducted with four to five seeds per hill and thinned to two per hill. Basal fertiliser applications were 50 kg urea, 50 kg TSP and 100 kg KCl per hectare. Weeding was done manually when required but usually twice in a season. Insecticide was applied at 10, 20, 40 and 60 days after sowing (DAS) and fungicide at 40 and 50 DAS in particular to control rust.

Gypsum application was made 7 days before rice harvest and organic mulch at a rate of 5 Mg ha^{-1} of rice straw was applied at sowing time. For tillage a single tyne implement drawn by a cow or a buffalo was used. Depth of tillage was approximately 20 cm.

2.2. Measurements

Agronomic characteristics were measured on five randomly selected plants and yield was determined from a harvested area of 2.5 m×2 m. Root length densities were determined at all sites. The 10 cm diameter cores which are 100 cm long were taken and cut into 10 cm increments. Soil and root were separated by washing and length of root determined using an image analysis technique (Kirchhof and Pender, 1992). Root length density was determined at the Maros, San Ildefonso and Manaoag sites only. Crop establishment was measured during thinning and crop survival was measured at harvest and expressed as the number of plants as a proportion of sown seeds (330,000 plants per hectare).

Soil strength was measured using a recording depth penetrometer (Rimik penetrometer) and the soil water content profile determined at the same time. The neutron moisture meter was used to measure the soil water content profile at the vegetative, initiation, flowering and maturity stages of growth.

2.3. Statistical analysis

Statistical analysis used comprised standard regression analysis and analysis of variance. The Duncan Multiple range test was used to compare treatment means.

3. Results and discussion

3.1. Effect of fertiliser application

A comparison of treatments T1 and T2 in each experiment provided a measure of the effect of fertiliser application on the yield of the three legumes. The results are shown in Table 2. Overall yields were relatively low, indicating that water stress was prob-

Table 2
The effect of fertiliser application on post-rice mungbean, soybean and peanut yield[a]

Location	Legume	Year	Yield (Mg ha^{-1})	
			Without fertiliser	With fertiliser
San Ildefonso	Mungbean	1992/1993	0.01	0.02
		1993/1994	0.39	0.14
		1994/1995	0.17	0.18
		Mean	0.19	0.11
Manaoag[b]	Mungbean	1994/1995	0.61	0.51
Maros	Mungbean	1992	0.29	0.28
		1993	0.34 a	0.42 b
		1994	0.42 a	0.54 b
		Mean	0.35	0.41
Jambegede	Mungbean	1992	0.56	0.55
		1993	0.72	0.60
		1994	0.70	0.84
		Mean	0.66	0.66
Jambegede	Peanut	1992	1.88	1.99
		1993	1.61 a	2.32 b
		1994	1.70	1.95
		Mean	1.73	2.09
Ngale	Mungbean	1992	0.76 a	1.08 b
		1993	0.38 a	0.90 b
		1994	0.46 a	1.04 b
		Mean	0.53	1.01
Ngale	Soybean	1992	0.94 a	1.33 b
		1993	0.30 a	0.63 b
		1994	0.49	0.61
		Mean	0.58	0.86

[a] Yields in the same line followed by different letters are significantly different at the p=5% level.

[b] Fertiliser was applied to all treatments in Manaoag in 1992/1993 and 1993/1994.

ably the dominant factor determining the yield of legumes under rainfed conditions on puddled soils.

At the Philippine sites (San Ildefonso and Manaoag) yield responses to fertiliser application were not significant. The dry soil conditions and absence of rain during the growing season (Schafer and Kirchhof, 2000, this issue) probably prevented the dissolution of the surface applied fertiliser and consequently these failed to reach the root zone. This suggested that application of the fertiliser prior to rice harvest may be a strategy to make fertiliser more readily available to the post-rice crop.

Grain yield of mungbean at the Maros site in Sulawesi was significantly increased through the application of fertiliser except during the growing season in 1992. The lack of fertiliser response in the first year (1991/1992) was probably due to late application of fertiliser. Fertiliser was applied immediately after sowing and probably did not dissolve adequately and remained unavailable to the crop, as at the sites in the Philippines. During the last 2 years (1993 and 1994) fertiliser was applied after rice harvest to ensure that it dissolved and reached the active part of the root zone sufficiently rapid. The average response to fertiliser was a 17% yield increase over non-fertilised plots and showed that residual fertiliser from the rice was inadequate to supply the requirements of dry season crops on these soils.

In Jambegede, a fertiliser effect was observed only in 1993 for peanut (Table 2). A significant effect of fertiliser on yield was observed in almost all cases at Ngale except for soybean in 1994 (Table 2). Yield increases were substantial at 42, 141 and 128% for mungbean in 1992, 1993 and 1994, respectively. For soybean, the increase in yield for 1992 and 1993 were 41 and 110%. Mean yields of mungbean were similar for the 3 years but for soybean, yields for 1993 and 1994 were approximately half of 1992. Mungbean is a 70-day crop whereas soybean a 90–100-day crop. In all 3 years, adequate rain fell during the mungbean growth cycle, but during the last 20 to 30 days of the soybean crop, rain fell only in 1992 (65 mm). This is most probably the reason for the higher mean yield in 1992. The fertiliser effect at Ngale was thought to be a combined effect of adequate rain during the growing season and a high water holding capacity of the Vertisol. It also clearly showed that residual fertiliser from the rice crop was a limiting factor.

3.2. Effect of soil amendment

Table 3 shows the effect of soil amendments on the yields of the three legumes by comparing T2, T3 and T4. At the Philippine sites San Ildefonso and Manaoag, the application of rice straw at the rate of 5 Mg ha^{-1} as surface mulch reduced weed infestation and significantly increased yield during the first year (1992/1993) and tended to increase yield in all

Table 3
The effect of soil amendment on post-rice mungbean, soybean and peanut yield[a]

Location	Legume	Year	Yield (Mg ha^{-1})		
			No amendment	Gypsum	Mulch
San Ildefonso	Mungbean	1992/1993	0.19 a	0.09 a	0.47 b
		1993/1994	0.44	0.35	0.52
		1994/1995	0.17	0.25	0.32
		Mean	0.27	0.23	0.44
Manaoag	Mungbean	1992/1993	0.72 a	0.25 b	0.94 c
		1993/1994	0.77	0.81	1.00
		1994/1995	0.51	0.62	0.52
		Mean	0.67	0.56	0.82
Maros	Mungbean	1992	0.28	0.28	0.30
		1993	0.42 a	0.52 b	0.53 b
		1994	0.54 a	0.57 b	0.76 c
		Mean	0.41	0.46	0.53
Jambegede	Mungbean	1992	0.55	0.47	0.47
		1993	0.60	0.67	0.50
		1994	0.85	0.94	0.72
		Mean	0.67	0.96	0.56
Jambegede	Peanut	1992	2.00	2.20	1.88
		1993	2.32	2.49	2.76
		1994	1.96	2.78	2.58
		Mean	2.09	2.49	2.41
Ngale	Mungbean	1992	1.08	1.07	1.13
		1993	0.89	0.88	0.82
		1994	1.04 a	0.74 b	0.20 c
		Mean	1.00	0.90	0.72
Ngale	Soybean	1992	1.33	1.34	1.38
		1993	0.63	0.83	1.09
		1994	0.62	0.66	1.06
		Mean	0.86	0.94	1.18

[a] Yields in the same line followed by different letters are significantly different at the $p=5\%$ level.

cases except in the last year (1994/1995) at the Manaoag site. As well as a technique to minimise weed infestation, mulch probably resulted in reduced evaporation maintaining wetter soil conditions with lower soil strength during the establishment stage of the crop, enabling it to exploit the available moisture of the profile at greater depths. At the Maros site, application of mulch increased grain yield and total biomass in the last 2 years. Compared to no mulch application these yield increases were substantial in the last two growing season, 26 and 33%. Similar to the observations at the Philippine sites, the mechanism through which mulch application increased yield is probably two-fold: conservation of soil water through reduced evaporation rates and improved weed control.

At the sites in East Java, Jambegede and Ngale, the application of gypsum or rice straw mulch did not affect mungbean yield except in 1994, where mulch reduced yield at Ngale. Yield of mungbean under mulch was very low at 0.20 Mg ha^{-1} compared to 1.04 and 0.74 Mg ha^{-1} for the nil amendment and gypsum treatments, respectively. It is possible that the excessively wet conditions coupled with mulch application resulted in favourable condition for fungal infestation leading to the observed poor crop emergence and establishment. In the case of soybean however, yields tended to be increased by mulch application, possible due to its water conservation effect later in the season when drier conditions prevailed. As discussed above, no rain fell during the 1994 period between mungbean and soybean harvests.

There was very little effect from the application of gypsum, except at Maros increased yields were observed in the 1993 and 1994 seasons and yield was decreased at Manaoag in the 1992/1993 season and at Ngale in 1994. The reasons for these opposing responses remained unclear, in particular since soil texture of the sites at Maros and Manaoag were similar. All soils had high base saturation and low exchangeable sodium percentages. Gypsum could be useful if the soil remained dispersed at the end of the rice-season due to high exchangeable sodium content. However, in these cases dispersion was probably caused by mechanical disturbance during puddling only and not by high levels of exchangeable sodium, thus reducing the benefits of gypsum application as a soil conditioner.

3.3. *Effect of sowing delay*

The effect of the length of the period between rice harvest and sowing the dry season legume was investigated by comparing treatments T2, T5 and T6. The mean response of mungbean to increasing delay time varied between sites. Increasing delay of sowing following rice harvest tended to decrease yields at the San Ildefonso site (Table 4). This was probably due to very poor soil physical conditions of the Vertisol soil under dry conditions. This hardsetting soil hardens rapidly upon drying. Therefore, crop establishment will be improved if sowing occurs under wet condition when soil strength is still low. For the experiments at the Philippine sites, rice was planted such that harvest would coincide with the end of the rainy season, with the legume sown at the start of the dry season. However, climatic conditions at the end of the wet season in the San Ildefonso area are generally erratic and the chances of establishment failures from heavy rainfall and typhoons are high. During the last year of trials at San Ildefonso (1994/1995), mungbean had to be re-sown on all treatments due extremely wet conditions caused by typhoon activity. Provided rainfall is not too extreme, adequate drainage for the mungbean crop may assist in avoiding the effect of heavy rain. However, what condition should be defined as too extreme, remained unclear. Mungbean yields were very low (<0.4 Mg ha^{-1}) suggesting that this area is not suitable for the introduction of legumes into the rice cropping system if planted at the end of the rainy season. However, since waterlogging is not a problem when sowing legumes in the rainy season in East Java (Rahmianna et al., 2000), sowing rice early followed immediately by mungbean may avoid the damaging effect of heavy rain on the mungbean crop. In the Philippines, the risk of damage from typhoons may also be reduced by early sowing of rice and the subsequent mungbean crop so that mungbean is already well established or nearing maturity when the chance of typhoons is greatest at the start of the dry wet season. Such a strategy can become feasible using techniques such as direct seeding of rice, early shallow cultivation prior to the onset of the rainy season to reduce water loss through bypass flow, and minimise the turn around period for sowing mungbean. Some farmers in the region are starting to experiment with the rice–mungbean

Table 4
The effect of sowing delay on post-rice mungbean, soybean and peanut yield[a]

Location	Legume	Year	Yield (Mg ha^{-1})		
			No delay	One week delay	Two weeks delay
San Ildefonso	Mungbean	1992/1993	0.03	0.02	0.02
		1993/1994	0.62 a	0.41 a	0.17 b
		1994/1995	0.24	0.17	0.11
		Mean	0.30	0.20	0.10
Manaoag	Mungbean	1992/1993	0.46 a	0.73 b	0.85 b
		1993/1994	0.96	0.77	0.89
		1994/1995	0.77	0.54	0.54
		Mean	0.73	0.68	0.76
Maros	Mungbean	1992	0.44 a	0.28 b	0.37 a
		1993	0.50 a	0.42 a	0.67 b
		1994	0.21 a	0.54 b	0.37 c
		Mean	0.38	0.41	0.47
Jambegede	Mungbean	1992	0.78 a	0.55 b	0.53 b
		1993	0.57 a	0.60 b	0.17 c
		1994	1.14 a	0.85 b	0.62 b
		Mean	0.83	0.67	0.44
Jambegede	Peanut	1992	1.98 a	1.99 a	1.55 b
		1993	3.44 a	2.32 b	1.47 c
		1994	2.38 a	1.95 b	1.73 c
		Mean	2.60	2.09	1.58
Ngale	Mungbean	1992	0.87	1.08	1.10
		1993	1.09	0.89	0.64
		1994	0.82	1.04	0.77
		Mean	0.93	1.00	0.84
Ngale	Soybean	1992	0.77	1.33	0.93
		1993	0.97	0.63	0.25
		1994	2.08	0.62	0.36
		Mean	1.27	0.86	0.51

[a] Yields in the same line followed by different letters are significantly different at the p=5% level.

system within the rainy season with a reasonable degree of success.

There was no discernible pattern for an optimum period of sowing delay on the silty clay loam at the Manaoag and Maros sites (Table 4). At Manaoag, the rainy season is short, but the soil is well structured and well drained, and the immediate surface is usually already dry during rice harvest. Soil water conditions in the topsoil and the success of establishment are therefore largely governed by rainfall. The most suitable time for sowing depends on climatic conditions and not on the time of sowing after rice harvest and these two factors tend to counter each other during the 3 years of the trial. Mungbean yields at Manaoag were reasonable with yields averaging around 0.7 Mg ha^{-1}. The low yields observed in Maros also indicated that post-rice mungbean production is not an economical proposition if sowing is delayed to the end of the rainy season or the beginning of the dry season. However, at the Maros site earlier sowing of mungbean after rice harvest was generally not possible due to the prevailing high watertables. It may be possible that soybean will be able to withstand such high watertables as shown in wet soil cultures (Troedson et al., 1989).

Observations from East Java at Jambegede and Ngale showed that increasing the delay in sowing legumes after rice harvest tends to reduce yield of all legumes, except at Ngale in 1992 (Table 4). The reason for the decrease is not clear but appears to be associated with excessive drying after sowing (Rahmianna et al., 2000). At Ngale, post-rice weather conditions in 1992 were drier during sowing than 1993 or 1994. A 50 mm rainstorm after D0 in 1992 resulted in poor establishment (40%) compared to D1 (95%) and D2 (96%). In contrast, a 55 mm rainstorm after D0 in 1993 and a 60 mm rainstorm after D1 in1994, resulted in high yields for D0 and D1 in 1993 and 1994, respectively.

On the lighter soils at Jambegede, poor establishment appears to be associated with a lack of rain after sowing, such as in 1993 when there was no rain after sowing and D2 gave 29% establishment. In all 3 years, the D0 treatments were preceded or followed by high rainfall resulting in the highest establishment rates and highest yields. At the sites in East Java, legumes were sown in the rainy season after rice harvest resulting in reasonably high yields of 0.65 and 0.92 Mg ha^{-1} for Jambegede and Ngale, respectively.

No doubt low yields were partly associated with the rate of survival but data was inadequate to draw any conclusion on this matter. In the absence of heavy rain and subsequent waterlogging increasing the sowing delay tends to reduce yield, probably associated with progressive soil drying and greater difficulty for roots to penetrate the compacted layer below the puddled zone. This would result in a reduced depth of rooting and water extraction. This pattern of drying is not as severe during the rainy season, nevertheless the decreasing pattern of rainfall towards the end of the rainy season (Schafer and Kirchhof, 2000) appears to be associated with drier soil conditions.

3.4. Tillage and sowing delay

The interaction of tillage and sowing delay was investigated by comparing treatments T2, T6, T7 and T8. At the Philippine sites, observation on the interaction between tillage and sowing delay were available only for the first year (Table 5). Although tillage increased yield at the San Ildefonso site, yields were extremely low and uneconomical. At Manaoag, tillage conducted early (1 week) after rice harvest had no effect on yield, while tillage conducted a week later, increased mungbean yield. The early tillage was done 2 days after 10 mm of rain and appears to have had no effect on establishment or yield, while the later tillage was done 1 day before rain resulting in better water penetration in the tilled soil and hence better establishment and yield. At Maros, tillage increased yield in 1993 only (Table 5).

At the sites in East Java, tillage had no effect on the yield of mungbean at either Ngale or Jambegede. Similarly at Ngale, soybean did not respond to till age. However, at Jambegede, peanut yielded higher when the soil was cultivated (Table 5). This may be associated with the better physical conditions (lower bulk density) for pod development. The interaction between tillage and sowing delay was not significant.

A comparison across the five sites indicate that tillage of wet soil or during a wet period does not affect the legume crop, however tillage of a dry soil followed by rainfall results in improved establishment and yield, presumably associated with better penetration and usage of rainfall by the tilled soil.

3.5. Root growth

At Maros, root growth was measured in the 1994 mungbean season at the vegetative stage. There were no treatment effects. However root length was clearly related to soil strength and depth (Fig. 1). Root length density decreased with depth which was concomitant with an increase in soil strength with depth, most probably associated largely with water content and bulk density changes with depth. The regression equation to express root length density as a function of depth had a coefficient of determination of 0.83. A best subset regression procedure was used to determine which other factors affected root length density significantly. Dummy variables according to the treatments applied such as fertilisation, soil amendment, delay and tillage, were included in the data array. Using these dummy variables, treatment were given a rating of 0 if the treatment was not applied or 1 if the treatment was applied. Thus all fertilised treatment would be given the value 1, and the non-fertilised treatment T1, the value 0. Mulch application improved the coefficient of determination from 0.83 to 0.90, the variable had a significance level of p=0.021 and was the only variable that contributed significantly to reducing variation for the prediction of root length density. The beneficial effect of mulch on root

Table 5
The effect of sowing delay and tillage on post-rice mungbean, soybean and peanut yield[a]

Location	Legume	Year	Yield (Mg ha^{-1})			
			One week delay		Two weeks delay	
			Zero till	Tillage	Zero till	Tillage
San Ildefonso[b]	Mungbean	1992/1993	0.02 a	0.08 b	0.02 a	0.08 b
Manaoag[b]	Mungbean	1992/1993	0.73 a	0.68 a	0.86 b	1.10 c
Maros	Mungbean	1992	0.28 a	0.37 b	0.43 b	0.41 b
		1993	0.42 a	0.67 b	0.52 c	0.71 b
		1994	0.54 a	0.37 b	0.50 ab	0.46 ab
		Mean	0.41	0.47	0.48	0.53
Jambegede	Mungbean	1992	0.55	0.43	0.53	0.45
		1993	0.60 a	0.42 a	0.17 b	0.11 b
		1994	0.84 a	0.89 a	0.61 ab	0.48 b
		Mean	0.66	0.58	0.44	0.35
Jambegede	Peanut	1992	1.99 a	1.81 bc	1.55 c	1.74 bc
		1993	2.23 a	2.75 a	1.47 b	2.00 a
		1994	1.94 a	3.03 b	1.72 c	2.89 b
		Mean	2.05	2.53	1.58	2.21
Ngale	Mungbean	1992	1.08	0.99	1.10	1.12
		1993	0.89	0.91	0.64	0.74
		1994	1.03 a	0.30 b	0.76 a	0.75 a
		Mean	1.00	0.73	0.83	0.87
Ngale	Soybean	1992	1.33 a	1.43 a	0.92 b	0.87 b
		1993	0.63 a	0.91 a	0.25 b	0.38 b
		1994	0.61	0.72	0.34	0.34
		Mean	0.86	1.02	0.50	0.53

[a] Yields in the same line followed by different letters are significantly different at the p=5% level.
[b] No tillage treatments applied in 1993/1994 and 1994/1995.

proliferation was most likely through the effect of mulch on soil water content, where the higher soil water contents under the mulch treatments resulted in lower soil strengths and thus reflected in yield (Table 3).

No significant treatment effects were observed on the Philippine sites. Depth of rooting at the San Ildefonso site was always limited to 30 cm. This limited depth of root proliferation and subsequent lack of subsoil water use was reflected in the poor yields at this site (0.01–0.4 Mg ha^{-1}). In contrast, on the silty soil at the Manaoag site, root growth was observed to a depth of 1 m. Yields were relatively high and associated with a greater use of residual subsoil water. The influence of root proliferation to depth and the associated yield was most pronounced in the 1994/1995 season when sowing delay treatments were compared (Fig. 2). The zero delay treatment had the greatest root length density and highest yield (Table 4). It is important to note that relatively high yields were achieved even under dry conditions and in the absence of rainfall during the mungbean phase, because roots were able to grow rapidly into the subsoil and use the residual subsoil water.

3.6. Crop establishment and climate

Oldeman (1975) suggested that 200 mm of rain is required to maintain submerged conditions and to meet the evapotranspirational demand of the submerged rice crop. A dry month is defined as having less than 100 mm rainfall. Using Oldeman's criteria, the climate at Jambegede and Ngale would fall in the C2 class (six wet and four dry months). Maros and San

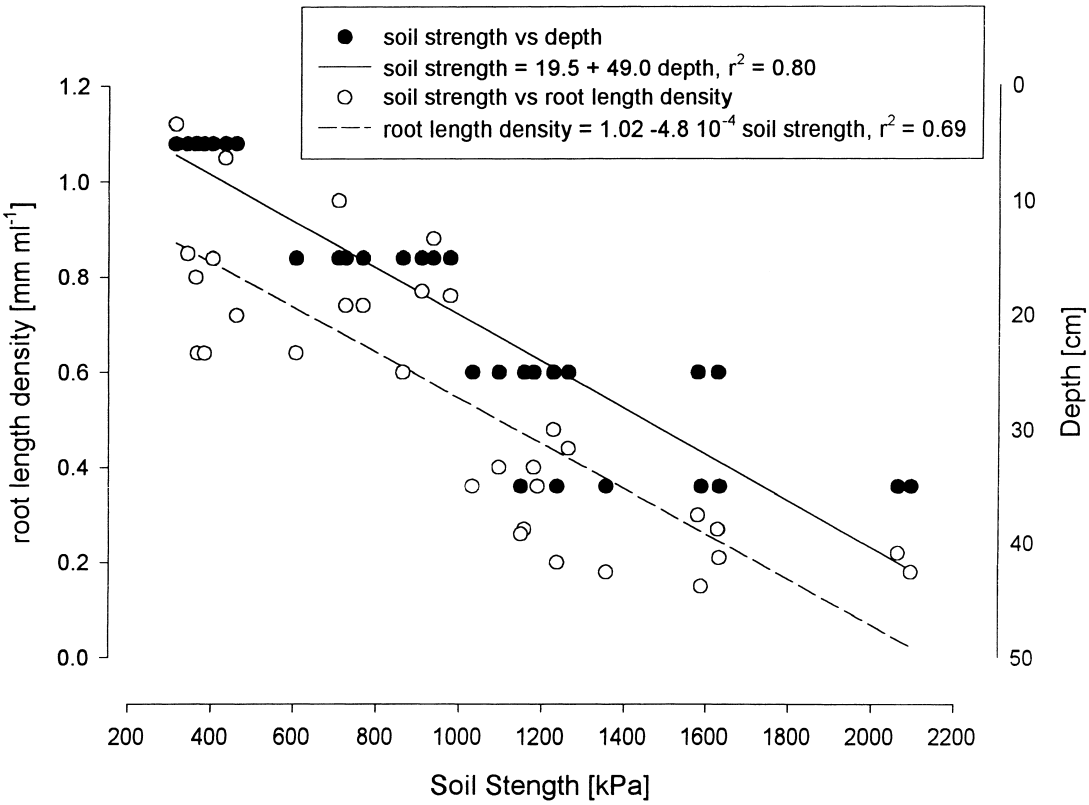

Fig. 1. The relationship between soil strength, root length density and depth at the Maros site.

Ildefonso in the slightly drier class C3 (six wet and five dry months), while Manaoag, Pangasinan province would be classified as D4 (three wet and eight dry months). These, or similar classification systems are generally employed to delineate production potential. A drawback of these classification systems is that they are based on averages and do not take year to year variation in rainfall into account. However, year to year variation can be very large, in particular in tropical areas.

Long term weekly rainfall data were compared to the weekly rainfall during the 3 months at which the legume crops were established. At Jambegede rainfall during the trial period was within the variation of rainfall that can be expected. However there was a tendency of the 3 years being slightly wetter than the average. The same applied to Ngale, except that the late wet season in 1994 tended to be wetter than average. Maros' weekly rainfall was also well within what can be expected, except for the wet period in 1992. At the sites in the Philippines, rainfall was within the expected pattern. Thus, taking variation into account, rainfall during the trial period did not deviate substantially from long term data.

Local practises were followed in terms of when rice and post-rice crops were planted or harvested. An important difference between the Indonesian and Philippines sites, however, was that post-rice legumes were planted in the latter part of the rainy season at Jambegede and Ngale (Indonesian sites) but at the start of the dry season at the Philippine sites, San Ildefonso and Manaoag and Maros (Schafer and Kirchhof, 2000). It is clear that rainfall around the sowing period is a major factor determining the water contents of the soil and hence the success of crop establishment. At Ngale and Jambegede, there was good rainfall during the mungbean crop in all 3 years, but the other sites had no or very little rainfall after sowing and particularly during the last month of the post-rice crop. At Maros, mungbean received some

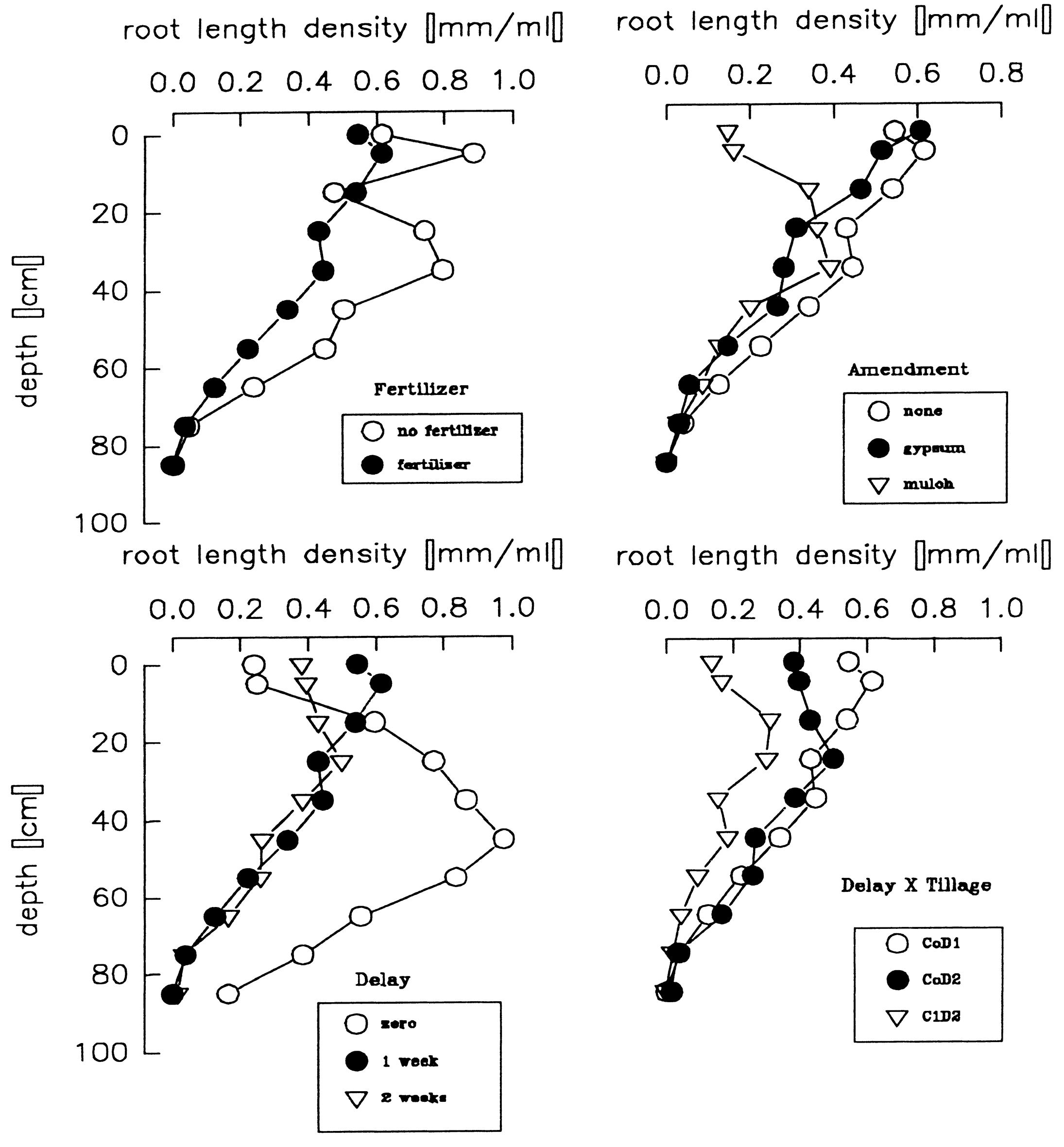

Fig. 2. The effect of fertiliser application, soil amendment, sowing delay and tillage on root length density of mungbean at flowering in Manaoag 1994/1995.

rainfall whereas at San Ildefonso and Manaoag mungbean grew almost entirely on stored water. Therefore it is not surprising that yields were moderate to high at Jambegede and Ngale as rainfall supplied most of the water requirement at Ngale and approximately half at Jambegede. Yield were low to very low at Maros and San Ildefonso as root growth was inadequate through the hard, puddled and compacted layers of these soils and access to subsoil water was poor. At Manaoag plants relied on stored water, but roots had no difficulty in growing to a depth of 1 m in this well drained soil.

To obtain an indication of how well crop establishment, crop survival, yield and seasonal rainfall were related, a correlation matrix for these weekly rainfall variables was calculated and given in Table 6. Crop establishment, survival and yield were strongly related to each other and showed the importance of establishment or survival for adequate yield. This was consistent with findings in the Philippines with mungbean (Bolton et al., 1985; IRRI, 1988) and for soybean (Carangall, 1985), which showed a linear increase in yield with increasing population density in the tropics. It is important to note that crop establishment and survival were measured independently from each other in these experiments. The strong relationship between these two parameters indicated that a similar proportion of established seedlings survived at all sites. Thus across the sites, survival appeared to be largely a crop characteristic. It may be dependent to a lesser extend on soil and climate within each site. Therefore crop establishment is a reasonable measure of plant population density and a major factor determining yield.

Crop survival is generally determined by both soil and climatic conditions that prevail after the crop is established. However, Table 6 shows that there was no relationship between rainfall following sowing and crop survival. Crop establishment and survival were both significantly related to rainfall before sowing. The relationship between survival and rainfall before sowing is probably due to the strong relationship between crop establishment and survival. It indicates that conditions leading to adequate crop establishment will result in an acceptable plant population density. The relationship between crop establishment and survival can probably be improved if establishment is further classified to include how well seedlings are established. Vigorous seedling can be expected to penetrate and access subsoil water reserves more readily than weak seedlings. The relationship between crop establishment and rainfall before sowing showed that an assessment of the soil water content and its suitability for sowing is the first step determining yield. It is a conscious decision the farmer is likely to make before sowing.

The lack of a relationship between establishment and rainfall after sowing is largely due to insufficient data available. The inclusion of additional climatic variables and clay content (as an indicator for plant available water) did not results in significant relationships again because of insufficient data.

Table 6 shows that yield is strongly related to crop establishment and survival with a correlation coefficient of 0.638 and 0.752, respectively. For a particular plant density, it is reasonable to assume that yield will also be determined by the amount of water available to the crop. In the absence of reliable data on water extraction from these experiments, surrogate parameters were used. The inclusion of clay content as a surrogate of plant available water capacity and seasonal rainfall improved the relationship significantly (Table 7), with the best relationship accounting for up to 74% of the variability in yield. This implies that the variation in root growth and water extraction between soil types are relatively small compared to the variation in available water between soil types. Hence

Table 6
The correlation coefficients for the relationship between crop establishment, survival, yield and rainfall during the dry season phase[a]

Explanatory variables	Variable to be explained		
	Crop establishment	Crop survival	Yield
Crop survival	0.845**	–	–
Yield	0.638**	0.752**	–
Rainfall in period			
One week before sowing	0.447*	0.406*	0.360
One week after sowing	0.122	0.131	0.234
Two weeks after sowing	0.192	0.275	0.327
Three weeks after sowing	0.106	0.146	0.278
Four weeks after sowing	0.066	0.106	0.228
Sowing to harvest	0.049	0.108	0.191

[a] N ranged from 43 to 55.
* $p<5\%$; ** $p<1\%$.

Table 7
Best subset regression equations to predict yield from survival or establishment, rainfall and clay content[a]

Independent variables	Regression coefficients for included dependent variable			
	Subset 1	Subset 2	Subset 3	Subset 4
Prediction using 'survival' as forced independent variable				
Constant (Mg ha^{-1})	−0.4857	−0.5089	−0.5700	−0.5217
Survival percentage (%)	0.0087	0.0084	0.0086	0.0086
Rain sowing to harvest (mm rainfall)				0.0002
Rain 4 weeks before harvest (mm rainfall)			0.0004	
Clay content topsoil (%)	0.0118		0.0126	0.0110
Clay content subsoil at 50 cm depth (%)		0.0102		
r^2 for included variables	0.71	0.69	0.72	0.73
Prediction using 'establishment' as forced independent variable				
Constant (Mg ha^{-1})	−0.5708	−0.5424	−0.6577	
Establishment percentage (%)	0.0059	0.0056	0.0057	
Rain 4 weeks before harvest (mm rainfall)			0.0005	
Clay content topsoil (%)	0.0141		0.0146	
Clay content of subsoil at 50 cm depth (%)		0.0114		
r^2 for included variables	0.62	0.58	0.64	

[a] Values are the regression coefficients for the independent variables in the appropriate regression equation.

a similar proportion of potentially available water would have been extracted from all soil types. It should be noted here that the plant available water capacity of these soils are filled at the start of the legume season because the soil was inundated for a period of at least 4 months. The regressions also imply that within each soil type, increasing rooting depth and water extraction should increase yield.

It would therefore be informative to deduce the range of possible contributions to mungbean yield from the relevant factors shown in Table 7 such as crop establishment, survival, rainfall and clay content providing nutrient supply is not limiting. The results in Table 8 indicate that the soil's clay content as a measure of plant available water after an extended period of inundation has potentially the largest effect on yield followed by plant population density as indicated by crop establishment or survival, while rainfall may have the smallest effect on yield. However, the influence of prevailing weather should not be underestimated as it appears obvious that extreme rainfall is likely to determine if the crop establishes after sowing. Further investigations within a modelling framework are needed to clarify the complex interactions of soil type, climate, crop establishment and survival.

Table 8
The range of possible yield contribution from rainfall, crop establishment and survival and clay content

Variable	Average regression coefficient	Range of variable		Range of yield contribution (Mg ha^{-1})	
		Minimum	Maximum	Minimum	Maximum
Survival percentage (%)	0.0086	0	96.3	0	0.83
Establishment percentage (%)	0.0060	0	100	0	0.60
Rain 4r weeks before harvest (mm rainfall)	0.0005	0	443	0	0.22
Sowing to harvest (mm rainfall)	0.0002	0	754	0	0.15
Clay content topsoil (%)	0.0155	40.7	73.9	0.63	1.15
Clay content subsoil at 50 cm depth (%)	0.0108	47.6	87.8	0.51	0.94

4. General discussion and conclusion

The application of fertiliser strongly increased legume yield on the sites in East Java. Yield increase was small in Sulawesi and there was no effect on the sites in the Philippines. This response seems to be associated with rainfall patterns during the legume phase. Gentle rain after sowing to the end of the rainy season in East Java provided wet conditions which dissolved the fertiliser and made it available within the root zone. With an adequate water supply, the availability of nutrients became the factor limiting yield, hence the response to fertiliser application. In Maros legumes were planted at the start of the dry season and rain was inadequate to move the fertiliser into the root zone. Due to the dry conditions during the legume season in the Philippines, applied fertiliser did not enter the root zone and thus yield remained unaffected. Furthermore, under such dry conditions water was the limiting factor determining growth and hence plants were not able to respond to an increase in fertiliser. However, these results indicated that residual fertiliser from the rice crop is probably insufficient under current management practices and can be a major limiting factor where water supply (rainfall or irrigation) is adequate.

The influence of climate on the effect of mulch application was directly opposite to the effect of fertilisation. Mulch increased yield in the drier areas (Philippines and Sulawesi), but had no effect in the wetter areas (East Java). If water is limiting, mulch will be beneficial by decreasing soil evaporation rates and thus conserving soil water.

Delay of sowing (turn around time for sowing) is often used to prescribe an optimum time after harvest when legumes should be sown. Recommendations on the turn around time for sowing legumes are based on the assumption that the soil will progressively become drier after rice harvest. Although this assumption is generally valid as sowing is conducted in the period of decreasing rainfall (see Section 3.3), particularly at the end of the rainy season or the beginning of the dry season, the temporal variability within each site associated with rainfall could mask this trend. Results from these experiments with 90–100 days rice cultivars, showed that delay per se was a poor indicator for describing soil water content at sowing, particularly when sowing is done during the rainy season. Paddies are generally drained about 1 week prior to harvest to allow easy access for harvesting. At harvest the soil is usually wet in the Indonesian sites. However, in the Philippines soil conditions were often dry during rice harvest which coincided with the end of the rainy season in these experiments. Rainfall following rice harvest and not time after harvest, determines the soil water content at sowing.

In East Java with a 6-month rainy season, legumes were sown within the remaining 2–3 months of the rainy season after 3.5 months of rice. This is consistent with the region's cropping system of rice–legume–legume. Legumes on these sites have moderate to high yields under the conditions of this experiment and relied on rainfall (Ngale) or a combination of rainfall and subsoil water (Jambegede).

In this experiment, legumes were sown at the end of the rainy season on the San Ildefonso and Maros sites. Yields were generally low as the crops suffered from poor establishment and terminal stress. Where long season rice cultivars (old cultivars of >150 days) are grown and harvested at the end of the rainy season, similar results could be expected. This suggests that early sowing of legumes on these sites would have increased rates of establishment and root growth into the moist soil and increased its yield potential. This suggestion is consistent with the observed success of some farmers who experimented with early sowing soon after rice harvest in these areas.

Manaoag has a 3-month rainy season which suits the modern rice cultivars. Although the legume was sown in the dry season at this site, the well structured and permeable soil allowed adequate establishment and root growth, resulting in moderate to high yields. The cooperating farmer was an excellent and experienced farmer who cares about the good structural condition of this soil and the success at this site must be attributed to some extend to his style of management.

It should be noted that the low plant population densities in these experiments at less than 330,000 plants/ha were deliberately selected to ensure that soil water will not be limiting at any of the sites as this would complicate comparisons between sites. The optimal plant population density for each soil climate combination will need to be determined independently. Therefore, the moderate yields of 0.65–0.92 Mg ha^{-1} yield average from the successful sites of Jambegede, Ngale and Manaoag might be increased by using higher sowing rates. Carangall (1985) showed that irrigated soybean yield in the Philippines increase linearly with population density up to 650,000 plants per hectare before showing a deviation from linearity and Bolton et al. (1985) showed that rainfed mungbean in the region near Manaoag showed a linear increase with a population of 250,000 plants per hectare without any indication of leveling. As mungbean is approximately four times more profitable than rice, yields of 1 Mg ha^{-1} should be acceptable to the farmers and should increase the farmer's income significantly. Further work is required to asses if early rice and mungbean planting can be used to avoid the detrimental effect of typhoons, which are a common feature in the region at the end of the rainy season. At Maros, the high watertables will be more suitable for soybeans rather than mungbean.

In conclusion, the results from the 3 years observations on five sites showed the following:

Crop establishment was shown to be the most limiting factor for post-rice crop production followed by the extraction of soil water, which is a function of root growth, and rainfall. The potential of soil types for the production of mungbean is a function of its clay content representing the potentially available soil water of that soil.

The establishment of legumes at the end of the rainy season or at the start of the dry season is not likely to succeed except on well drained and well structured soils such as the Manaoag soil. Sowing immediately after rice harvest in the rainy season will ensure high establishment rates and yield. It also appears that a sufficiently long period of rainfall will be necessary to ensure adequate root development and extraction of the residual subsoil water. Based on the observation that mungbean requires 30 days before its first stage of harvest, it is reasonable to assume that a minimum of 4 months rainy season will be required for a successful rainfed rice–mungbean rotation.

The residual fertility after lowland rice is generally inadequate for the dry season legume crop and additional fertilisers is required to achieve high yields from dry season legumes.

Mulch or tillage has no effect on the growth of legumes after rice in the higher rainfall areas or during the rainy season. Mulch may affect legume growth and yield in the dry season.

These conclusions are based largely on the effect of treatments on the potential supply of water to the legume crop. Thus, rainfall distribution can be used to delineate or classify regions where mungbean can potentially be grown after rice. Furthermore the probability of success can be evaluated based on a probabilistic evaluation of rainfall uncertainty as well as other agronomic factors that may be considered important in specific areas.

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