GERMINATION AND ESTABLISHMENT OF LEGUMES AFTER RICE UNDER RAINFED RICE SYSTEMS: A REVIEW OF LITERATURE

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SUMMARY

Crop establishment that occurs during the first three weeks of the growing phase depends on the success of seed germination and seedling emergence. As the first process, germination can be obtained only when the seed absorb water at a sufficiently rapid rate to reach minimum or critical water content, before other biotic factors can prevent its completion. In this regards, high quality of seeds is an ultimate prerequisite. It is recognized that germination and crop establishment are dominated by physical processes and therefore soil physical properties around the seed and the very young seedling govern the success. Strictly speaking, seed germination and early crop establishment are a function of soil physical condition and seed quality.

A rainfed rice ecosystem is essentially a rice field with rainfall as the main source of water to flood the field prior to and during the period of paddy rice growth. This ecosystem is characterized by a lack of water control and therefore flooding and drought are potential problems. About 70 to 75% of the rice farms in Asia are rainfed due to inadequate irrigation systems. Since rice has limited success if planted after the wet season without any irrigation, farmers cultivate upland crops in lowland areas after rice that capable of coping with the dry soil during the later part of the growing season as well as to obtain additional income to support their families.

Legumes are the most popular dry season crops in rainfed lowland rice-based cropping systems, as farmers expect the crops to rely on stored water left after rice. In reality, the performance of legume crops in rainfed lowland rice-based cropping systems is generally poor. It should be remembered that puddling of the soil in flooded rice fields is an integral part of rice farming in Asia. This results in waterlogged soils and poor soil physical conditions after rice, lead to the compacted and hard soils following drying. These waterlogged conditions and hard soil, together with low seed quality and fungal attack, significantly affect germination and emergence of legume crops. To obtain high crop establishment, farmers manipulate the soil physical conditions using several practices such as soil tillage, build ditches with the various levels of success.

INTRODUCTION

One-third of the world's rice areas are rainfed and most are located in South and Southeast Asia (Barker and Herdt 1979; IRRI 1989; IRRI 1993). In these rice fields, water is provided in a flooded rice system and due to rainfall pattern, only a single flooded rice crop is practiced. Since water is less available for the following lowland rice cultivation, farmers in many parts of Asia grow upland crops which need less water compared to rice.

Legume crops are very popular as upland crops and when planted during the drier periods of the year, they can exploit the stored water in the profile (Jayasuriya and Maranan 1982; Buresh and De Datta 1991; Cook *et al.* 1995). Planting upland crops is usually done when the soil is relatively wet and sometimes still in a saturated conditions. Hence, seedlings are often damaged by the very wet soil condition. However, if planting is done when the soil water content is favourable for cultivation, it is possible that the crop may suffer from drought stress during the later stages of growth (Zandstra 1982; Hundal and Tomar 1985; Buresh and De Datta 1991). Therefore, appropriate planting techniques are very important in this wet condition.

Crop establishment consists of three development phases: (1) seed germination, (2) seedling emergence and (3) early seedling growth (Trouse 1971; So 1987; Wood *et al.* 1992). Germination and emergence, followed by high crop establishment are very important factors in obtaining high yields, especially for single tiller plants where yield is positively correlated with plant density. Root growth also cannot be ignored as a factor in the success of crop production since roots serve as a means for water and nutrient absorption and as an anchor for the plant stand.

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The seed must absorb water at a sufficiently rapid rate to reach a minimum or critical water content for successful germination before other biotic factors can prevent its completion. Once germination occurs it should be followed by coleoptile or hypocotyl development and these must be able to penetrate the overlying soil before they run out of seed reserves (So 1987). Germination and crop establishment require suitable environmental conditions for the plant to emerge and grow until the first true leaf appears. The general soil physical conditions that contribute to success are soil temperature, soil water potential, soil oxygen concentration, soil strength and seed-soil contact area (So 1987). Good seed quality of course a prerequisite (Basu 1995; McDonald and Copeland 1997).

This review will discuss the potential of lowland rice fields as the area for planting legumes crops, the performance of upland crops planted into lowland rice fields after rice, the constraints and alternate solutions for legume crop planted in lowland rice-based systems as well as program and strategy for the success of crop establishment of legumes in lowland rice-based systems.

THE POTENTIAL OF LOWLAND RICE-BASED SYSTEMS FOR PLANTING LEGUMES CROPS

Rice is the most important staple food crop for most of Asian people and 90% to 92% of the world's rice is produced in Asia (Carangal 1977; IRRI 1993). Around 80% of the world's rice is grown as paddy or lowland rice which 55% as irrigated lowland rice and 25% as rainfed lowland rice, in contrast to dryland or upland rice which represent around 12% (IRRI 1993). Either irrigation and/or rain are used to flood the lowland rice fields so that puddling can be done before the rice seedlings are transplanted. In non-irrigated areas, however, rice is grown under rainfed conditions during the rainy season. Only around one-third of irrigated lowland rice fields receive a year-round irrigation which would allow three rice crops to be grown within one year or five rice crops in two years. The other areas permit only one or two rice crops per year (IRRI 1993).

A rainfed rice ecosystem is essentially a rice field with rainfall as the main source of water to flood the field prior to and during the period of paddy rice growth. This ecosystem is characterized by a lack of water control and therefore flooding and drought are potential problems. A second rice crop is possible in the post rainy season when supplementary irrigation is available during the crop growth phase.

About 70 to 75% of the rice farms in Asia are rainfed due to inadequate irrigation systems. This limits farmers to only single rice crop per year (Carangal 1977; Garrity and Liboon 1995). Since rice has limited success if planted after the wet season without any irrigation, farmers cultivate upland crops in lowland areas after rice to obtain additional income to support their families (Carangal 1977; Jayasuriya and Maranan 1982; Buresh and De Datta 1991). Unfortunately, this practice is only done in a small fraction of rice fields, with the majority of other fields left fallow after the rice harvest in South and Southeast Asia (Carangal 1977; Garrity and Liboon 1995). The main reasons for this are lack of water and the difficulty in land preparation caused by the adverse soil physical conditions left after rice. Fallow not only leaves the productive land idle for the rest of the year, but also means that farmers fail to gain any additional income from the land during the dry season (Muslem Uddin Miah 1991).

Puddling of the soil in flooded rice fields is an integral part of rice farming. Asian farmers practice this activity as a traditional method for wet land preparation for growing rice to promote easy transplanting, weed control and to reduce water percolation losses and to increase nutrient availability (De Datta and Barker 1978; IRRI 1993). The disadvantages of puddling are the high water requirement, soil structural degradation, and high soil strength upon drying (Greenland 1980). Puddling, especially in rainfed wetland areas, is most likely to delay rice planting and to require a higher cost of labour for puddling (De Datta *et al.* 1979). In addition, puddled soils will often impede root development (De Datta and Barker 1978).

THE PERFORMANCE OF LEGUME CROP AFTER RICE IN LOWLAND RICE-BASED SYSTEMS

Legumes are the most popular dry season crops in rainfed lowland rice-based cropping systems, and are mostly planted under rainfed conditions and rely on stored water left after rice (Pasaribu and McIntosh 1986; McWilliam and Dillon 1987; Wood and Myers 1987; Buresh and De Datta 1991). Legume crops can be grown in rice-based cropping systems either preceding, or following rice, depending on water availability. As a source of food, animal feed, biological fertiliser and soil degradation ameliorant, legume crops can improve a farmer's income (Buresh and De Datta 1991; Chandrasekaran *et al.* 1996).

The major food legume crops grown on rice fields in Asia are soybean, mungbean, peanut and cowpea (Buresh and De Datta 1991). In Indonesia, and particularly in the Philippines, mungbean is a common upland crop planted after lowland rice during the dry season. Its short growing period of 60 to 65 days is the main reason for its superiority over other legumes as its water demand is comparable with the residual water left after the wetland rice crop. Poor crop stands and low management inputs give rise to low yields ranging from 0.3 to 0.8 t/ha in the Philippines (Obcemea *et al.* 1996, Sanidad 1996) and less than 1 t/ha in Indonesia (Radjit 1994).

Soybean is the main upland crop planted after lowland rice in the Philippines and Thailand with around 0.8 t/ha being harvested from Thai farmers' fields (Smitobol 1991; Benjasil *et al.* 1992; Escano *et al.* 1992; Virakul 1992). Soybean is the most popular legume among Indonesian farmers with about 60% of the total soybean areas planted into wetland areas during the first or second dry season after paddy rice (Sumarno *et al.* 1988; Irawan and Lancon 1992). Despite the fact that it is planted as a source of cash income and cheap high-quality protein, its productivity of around 1.1 t/ha is still lower than its potential yield which up to 2.7 t/ha (Pasandaran *et al.* 1992; Sumarno and Adisarwanto 1992; Suhartina 2005**).** The low yields are due to factors such as poor plant stand caused by inadequate seed germination, excess water at planting and poor seed-soil contact (Pasaribu and McIntosh 1986; Sumarno and Adisarwanto 1992). Maize and peanuts are two other main upland crops planted after rice with no irrigation in some regions of Indonesia (Sudjadi *et al.* 1991).

Legumes can be grown with zero, minimum or intensive tillage. In lowland rice areas, zero tillage with the seeds being broadcast after or before the rice harvest is popular among Asian farmers. This practise significantly reduces the risk of crop failure in the later stages of growth due to drought and saves the labour involved in land preparation. Zero tillage is done to take advantage of the residual water left after rice and generally results in better germination due to better soil water and aeration conditions (Nizami 1991; Palaniappan 1991; Smitobol 1991). In irrigated areas, however, intensive tillage is recommended, as water is available throughout the legume-growing season (Carangal *et al.* 1987).

In summary, the performance of legume crops in rainfed lowland rice-based cropping systems is generally poor. Generally speaking, both governments and farmers pay less attention to legume crops because their status as secondary crops. This is resulting in lower inputs and management levels and little investment in the practice (Jayasuriya and Maranan 1982). These factors, together with adverse soil moisture and soil structure conditions, are unlikely to improve legume yields. Technical problems such as inappropriate land preparation after the lowland rice harvest, waterlogging and drought stress entirely contribute to their low performance (Carangal *et al.* 1987; McWilliam and Dillon 1987; Wood and Myers 1987).

THE CONSTRAINTS AND ALTERNATE SOLUTIONS FOR LEGUME CROP PLANTED IN LOWLAND RICE-BASED SYSTEMS

a. Poor crop establishment of legumes crop

Poor crop establishment is identified as one major problem for production of grain legumes after rainfed lowland rice in rice-based cropping systems (Greenland 1985; Carangal 1986; Fyfield and Gregory 1989; Fyfield *et al.* 1990). Poor establishment might result from poor germination, successful germination not followed by seedling emergence, or emergence followed by poor early seedling growth.

In general, poor germination and poor establishment are caused by four factors: (1) inferior seed quality and physical seed damage; (2) seed fungal and pest infections; (3) unfavorable physical environment viz. excessive soil moisture, excessive cloddiness, high soil strength, crusted soils; and (4) poor management such as inappropriate land preparation and method and depth of planting (Wood and Myers 1987; Sumarno and Adisarwanto 1992; Garrity and Libbon 1995; Tisdall 1996).

Sowing an upland crop into lowland soil under zero tillage means that the legume crop will have to be sown early, when the soil is still wet. In this situation, germination and emergence may be completed before the soil dries out. Early emergence and establishment is also beneficial for root growth, as the roots can proliferate while the soil is still wet. In reality, poor crop establishment is usually the main problem. Wet conditions due to rain during the early part of the dry season following the rice harvest are the main causes of poor germination and/or establishment (Lantican 1982). To reduce waterlogged conditions at planting and to improve establishment of legume crops, farmers usually build ditches, plant in ridges or cultivate the land (Zandra 1978; Pushparajah and Sompongse 1991).

To be successful, conventional seeding method can be practiced only on drained soils suitable for tillage or seeding implements (IRRI 1992). This means that wet paddy fields require a long turn around period (TAP) to reach soil moisture conditions suitable for optimum seedbed preparation (Pagliai and Painuli 1988). Planting late, therefore, ensures good establishment but there is the possibility of drought stress during the later stages of growth. In contrast, cultivation when the soil is wet results in excessively cloddy structure of the surface soil, especially on clay soils. Hot weather dries the clods and hardens the surface quickly. A hard cloddy seedbed is undesirable for seed and soil contact and will reduce germination of upland crops. If germination succeeds, the hard surface soil may hinder seedling emergence and adversely affect the final establishment (So and Woodhead 1987; Pagliai and Painuli 1988). In turn, poor crop establishment results in low plant populations, which will lead to low yields, particularly with single tiller crop plants.

Poor crop establishment caused by adverse soil physical conditions such as structural changes, waterlogging and soil hardening resulted from puddling activity is the major contributor to low legume yields planted in rainfed areas after lowland rice (Kirchhof and So 1995; So and Ringrose-Voase 1996). Even though the importance of crop establishment on legume yield is well established, most research is still focusing on increasing yield through optimizing the cultural practices. These include fertilizer, irrigation, soil tillage, pest, disease and weed control, variety improvement, and water management with little work being done on crop establishment. To obtain a high plant population, farmers apply significantly higher numbers of seed than recommended, and consequently increase the production cost.

Seed germination and early crop establishment are a function of soil physical condition and seed quality. Control of biotic factors is required for the satisfactory completion of the process of crop establishment (Bewley and Black 1994). For successful establishment on a farm it is important to use a suitable implement to sow the crop (Tisdall 1996).

b. Waterlogged conditions and hard soil

Waterlogging, quick drying of the surface soil, massive soil and cloddy seedbeds caused by poor soil cultivation are the most common soil conditions in rainfed lowlands after rice (Hundal and Tomar 1985; Sumarno and Adisarwanto 1992; Garrity and Liboon 1995). These conditions are detrimental to germination and establishment of subsequent legume crops (So and Woodhead 1987; Cook *et al.* 1995; So and Ringrose-Voase 1996). Residual soil water after the lowland rice has been harvested together with rain during the early part of the dry season results in a high soil water contents at the seed zone. This condition is a constraint for seed germination and seedling emergence because the saturated soil is poorly aerated and this limits oxygen supply to the germinating seeds and slows the metabolic processes during germination and establishment of the legume crop. The seed will not germinate, or the emerging seedling may be killed, as a result of an oxygen shortage in very wet or waterlogged soil (Corbineau and Come 1995). Under such anaerobic conditions, the metabolic processes leading to germination and early seedling growth are adversely affected and quite often the seed dies before germinating because of fungal infection (Bewley and Black 1994). Wet and warm conditions are disadvantageous, especially for lower seed quality, as they stimulate fungal attack, which can result in seed rotting before germination occurs (So 1987). Waterlogged conditions reduce germination and emergence (Corbineau and Come 1995). In a very dry soil, seed will not germinate because imbibition cannot occur. The importance of water in the germination process is clearly demonstrated by the crop stand (Bouaziz *et al.* 1990). The depletion of soil water content reduces the rate of imbibition and delays germination and emergence, possibly leading to an uneven or spotty stands (Collis-George and Hector 1966).

High levels of solar radiation hasten evaporation and increase soil temperature at the soil surface and increase the rate of the soil drying and hardening. Quick drying of puddled soils produces a hard massive soil with high mechanical impedance and high soil surface temperature. Such hard soils delay germination, especially the swelling process and sometimes coleoptile or hypocotyl damage occurs (Cook *et al.* 1995; Townend *et al.* 1996). The problem is more pronounced in silt soils, which form crusts and are hardsetting and these may hinder seedling emergence. Therefore, planting time for upland crops after rice in rainfed lowland rice based cropping systems during the dry season should be considered as an important factor (Brar *et al.* 1991).

In rainfed lowland areas that are dominated by clay soils, good seedbed condition is important for germination and emergence of legume crops planted in puddled soil after rice. In a non-tilled soil, emergence will be reduced and coleoptile or hypocotyl damage increased as a result of increasing soil strength at the surface soil following drying of the soil (So 1987; Cook *et al.* 1995; Nasr and Selles 1995). Early germination and rapid hypocotyl growth therefore, are the main prerequisites to achieve successful emergence in soils having a high mechanical resistance on drying, enabling emergence to be completed before the soil gets hard (Townend *et al.* 1996).

Minimum or conventional tillage, on the other hand, results in a cloddy soil surface with large soil clods that dry easily. These rough seedbeds affect germination due to poor seed and soil water contact (Sharma *et al.* 1988). Emergence is inhibited as hypocotyl penetration is prevented or the length of path for hypocotyl to come up to soil surface is greatly increased (Nasr and Selles 1995).

Waterlogged soils and poor soil physical conditions after rice generate poor crop establishment that later on reduces legume production (Patanothai and Ong 1987). Wet conditions, which may last for excessively long periods, especially in fine-textured clayey soils, can lead to compacted and hard soils following drying (De Datta and Barker 1978). Soil tillage, therefore, will be required to create a friable seedbed for the establishment of a legume crop. However, if tillage is done when the soil water content is suitable for tilling, it may be too late for planting the legume crop because of the possibility of serious drought stress during later stages of growth. Tillage done early on wet soils will result in rough seedbeds when dry and can lead to a low seedling number and low productivity (Dong-Mai 1991).

Including a legume crop into rice-based cropping systems requires good physical management of the soil after the rice crop (Zansdra 1978). This consists of draining the saturated soil to produce a drained and well-aerated soil and cultivating the hard and massive soils to obtain a friable structure suitable as a seedbed for the legume crop. Removal of the plough pan is also necessary to avoid waterlogging during legume germination and establishment and to enhance root growth in the later stages of growth (So and Woodhead 1987; Pushparajah and Sompongse 1991).

c. Inappropriate planting technique

The seed planting technique adopted by farmer is an important factor affecting the success of the legume crop establishment. How a seed germinates and grows under the conditions created by each method of planting should be considered as an important factor. The two most widely adopted techniques in Asian countries are broadcasting and dibbling the seeds either in rows or randomly into the standing rice crop before harvesting or after rice harvest (Syarifuddin 1982; Carangal *et al.* 1987; Sumarno *et al.* 1988; Palaniappan 1991; Benjasil *et al.* 1992; Chainuvati 1992; Gypmantasiri 1992; Irawan and Lancon 1992; Sarobol *et al.* 1992; Sumarno and Adisarwanto 1992; Virakul 1992; Sanidad 1996).

In Indonesia, despite reducing the number of plants because of the failure of the seeds to germinate, the broadcasting method is recommended when the soil is not adequately drained (Syarifuddin 1982; Sumarno *et al.* 1988; Suyamto *et al.* 1989). Broadcasting results in a poor spatial distribution, poor seed-soil contact, uneven seeding depth and excessive seed loss by ants and birds (Cardwell 1984; Smitobol 1991; Partley and Cobin 1994). Sowing by dibbling is time consuming, labour intensive and requires extra expense for ash/compost/straw to ensure adequate seed-hole cover (Benjasil *et al.* 1992; Gypmantasiri 1992). In addition, delays in sowing may result in increasing soil strength of the puddled rice fields due to soil drying (Garrity and Liboon 1995). Sometimes dibbling is done immediately after the rice harvest with no land preparation when the soils are very soft and fully saturated (Pasaribu and McIntosh 1986; Palaniappan 1991; Garrity and Liboon 1995). A recommended practice in Indonesia for grain legumes after lowland rice is dibbling the legume into well-drained soil (Suyamto *et al.* 1989; Sumarno 1991; Irawan and Lancon 1992).

Potentially, dibbling should result in better establishment than the broadcast method, as seeds are less exposed and spatial distribution of plants is superior. The variable success of dibbling in the farmers' fields has been associated with a lack of consistency in the method adopted. An improved dibbling method should therefore increase establishment and crop yield.

PROGRAM AND STRATEGY FOR THE SUCCESS OF CROP ESTABLISHMENT OF LEGUMES IN LOWLAND RICE-BASED SYSTEMS

It is realized that planting technique is as an important factor in determining the success of seed germination and seedling emergence. The seed hole created by the planting tool should give suitable physical conditions for germination and emergence. The relevant strategy to the success of seed germination and crop establishment is by creating a seed hole in such a way so that the seed-soil water contact is perfect.

Puddling that integrates to most Asian rice farmers give both the advantage and disadvantage in the farming activities. The advantage of puddling to wetland rice crops among others are facilitate the transplanting of rice seedlings, to control weeds, to reduce water and nutrient losses through percolation, to hold water especially under rainfed conditions. The disadvantage is pronounce especially on drying that the puddled soil has a high bulk density, a low infiltration rate with poor aeration, a surface soil crust and can also be hard-setting (Sanchez 1973; De Datta and Barker 1978; Pagliai and Painuli 1988; Pushparajah and Sompongse 1991). The strategy is that possible to reduce the puddling when wetland rice is going to grow?

The presence of crop establishment model would be very welcome. To develop a suitable crop establishment model, it is required quantitative data on the effects of the major factors on imbibition, germination, emergence and establishment. Whilst, the optimal soil physical properties necessary for crop establishment can be assessed under controlled conditions in the laboratory. Once they are formulated, a crop establishment model can then be proposed. The developed model is used to identify key management practices that strongly influence germination, emergence and crop establishment and hopefully it helps identify solutions to problems with the rainfed lowland rice-based cropping system, providing the quality of the seed lots uses high and the same in all cases.

CONCLUSION

1. Planting a legume soon after the rice harvest, without any soil tillage and under waterlogged conditions can impair its germination and emergence, which then results in poor establishment. When legume seeding is delayed sufficiently to allow the soil to dry to optimum moisture content, soil strength of the puddled rice fields is rapidly increase. This high soil strength has a significant role in reducing seedling emergence and their root growth.
2. Soil tillage is usually undertaken to provide a suitable soil physical condition for legumes, and it can be done when soil water contents have fallen below a certain level. Planting late in these tilled soils will expose legumes to drought stress during the later stages of growth.
3. Favorable soil temperatures, aeration, and adequate water uptake play an important role in the success of germination and early growth of new seedlings. The physical conditions of the seedbed, such as its soil water potential and its strength, influence the subsequent hypocotyl growth and emergence. A high soil water content combined with an optimum temperature will hasten seed germination and emergence. High soil water content in poor structured soils governs the development of soil strength which plays a crucial role in seedling emergence processes under this cropping system.

BIBLIOGRAPHY

Barker, R., and Herdt, R.W. 1979. Rainfed lowland rice as a research priority –an economist's view. *In* Rainfed Lowland Rice. Selected papers from the 1978 International Rice Research Conference. IRRI. The Philipp.: Los Banos.

Basu, R.N. 1995. Seed viability. pp. 1–44. *In*. A. S. Basra (Ed.). Seed Quality: Basic Mechanisms and Agricultural Implications. Food product Press: New York.

Benjasil, V., Pintongkam, S., Seradee, I., Potan, N., Tongprew, N., Nattriphob, P., and Kajornmalee, V. 1992. Technology available for increasing soybean production and farmers' incomes in the north of Thailand. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3–6, 1991. CGPRT Centre: Bogor.

Bewley, J.D., and Black, M. 1994. Seeds. Physiology of Development and Germination. Second Ed. Plenum Press. New York. 445 p.

Bouaziz, A., Souty, N., and Hicks, D. 1990. Emergence force exerted by wheat seedlings. *Soil and Tillage Research* 17, 211-9.

Brar, G.S., Gomez, J.F., McMichael, B.L., Matches, A.G., and Taylor, H.M. 1991. Germination of twenty legumes as influenced by temperature. *Agronomy Journal*, 83, 173–5.

Buresh, R.J., and De Datta, S.K. 1991. Nitrogen dynamics and management in rice-legume cropping systems. *Advances in Agronomy* 45, 2–59.

Carangal V.R. 1986. Soybean in rice-based farming systems: The IRRI experience. *In* Soybean in Tropical and Sub-tropical Cropping Systems. Proc. of A Symposium. Tsukuba, Japan. The Asian Vegetable Res. and Dev. Centre. Shanhua.

Carangal, V.R. 1977. The Asian cropping systems network. *In* Cropping Systems Research and Development for the Asian Rice Farmer. IRRI. The Philip.: Los Banos. pp. 31–48.

Carangal, V.R., Rao, M.V., and Siwi, B.H. 1987. Limits imposed by climatological factors. *In* E.S. Wallis, and D.E. Byth (Eds.). Food Legume Improvement in Asian Farming Systems Proc. of an International Workshop held at Khon Kaen, Thailand, 1–5 September 1986. ACIAR Proc. No. 18.

Cardwell, V. B. 1984. Seed germination and crop production. *In* M. B. Tesar (Ed.) Physiological Basis of Crop Growth and Development. Am. Soc. of Agron. Crop Sci. Soc. of Am. Madison.

Chainuvati, C. 1992. Soybean extension program in Thailand. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3–6, 1991. CGPRT Centre, Bogor.

Chandrasekaran, B. Bhattacharyya, H.C. Gogoi, J.K. and Sankaran, S. 1996. Problems of and prospects for soil management for lowland rice-pulse rotations. *In*: G. Kirchhof and H.B. So.(Eds.). Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems. Proc. of a workshop held at the Bureau of Soil and Water management, Quezon City, Manila, 20–24 November 1995. ACIAR Proc. No. 70.

Collis-George, N., and Hector, J.B. 1966. Germination of seeds as influenced by matric potential and by area of contact between seed and soil water. *Australian J. of Soil Res.* 4, 145–64.

Cook, S.M.F., Gupta, S.C., Woodhead, T., and Larson, W. E. 1995. Soil physical constraints to establishment of mungbeans (*Vigna radiata* L. Wilzek) in paddy rice (*Oryza sativa* L.) soils. *Soil and Tillage Research* 33, 47–64.

Corbineau, F., Picard, M.A., Bonnet, A., and Come, D. 1995. Effects of production factors on germination responses of carrot seeds to temperature and oxygen. *Seed Science Research* 5, 129–35.

De Datta, S.K., and Barker, R. 1978. Land preparation for rice soils. *In* Soil and Rice. IRRI Phill.: Los Banos.

De Datta, S.K., Morris, R.A., and Barker, R. 1979. Land preparation and crop establishment for rainfed lowland rice. pp. 189–214. *In*. Rainfed Lowland Rice: Selected papers from the 1978 International Rice Research Conference. International Rice Research Institute: Los Banos.

Dong-Mai, H. 1991. Current situation and problems of post rice soil and crop management on Vertisols in Jiangsu Province, China. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

Fyfield, T.P., and Gregory, P.J. 1989. Effects of temperature and water potential on germination, radicle elongation and emergence of mungbean. *Journal of Experimental Botany*, 40, 667-74.

Fyfield, T.P., Gregory, P.J., Woodhead, T., and Pasuquin, E.M. 1990. Effects of tillage, seeding method and time of sowing on the establishment of mungbean in drying, previously puddled soil. *Soil and Tillage Research*, 18, 333–46.

Garrity, D.P., and Liboon, S.P. 1995. A non conventional method for establishing upland crops following lowland rice in saturated soils. *Field Crops Research* 43, 31–42.

Greenland, D.J. 1980. Recent progress in studies of soil structure, and its relation to properties and management of paddy soils. pp. 42–58. *In* Institute of Soil Science, Academia Sinica (Ed.). Proc. of Symposium on Paddy Soil. Springer-Verlag: New York.

Greenland, D.J. 1985. Physical aspects of soil management for rice-based cropping systems. pp. 1–16. In Soil Physics and Rice. IRRI The Philipp.: Los Banos.

Gypmantasiri, P. 1992. Soybean farming systems in the upper north of Thailand. pp.317–32. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3–6, 1991. CGPRT Centre, Bogor.

Hundal, S.S., and Tomar, V.S. 1985. Soil water management in rauin-fed rice-based cropping systems. pp. 337–50. *In* Soil Physics and Rice. IRRI The Philipp. Los Banos.

International Rice Research Institute. 1989. IRRI Toward 2000 and Beyond. IRRI. The Philip.: Los Banos.

International Rice Research Institute. 1992. Program Report for 1991. IRRI. The Philip.: Los Banos.

International Rice Research Institute. 1993. 1993-1995 IRRI Almanac. IRRI. The Philip.: Los Banos.

Irawan, B., and Lancon, F. 1992. The constraints in growing soybean and their impact on the efficiency of soybean cultural practices: The case of Japanan in East Java. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3-6, 1991. CGPRT Centre: Bogor.

Jayasuriya, S., and Maranan, C. 1982. Economics of upland crops in rice-based cropping systems. *In* Cropping Systems Research in Asia. Report of a Workshop on Cropping Systems Research in Asia. IRRI The Philipp.: Los Banos.

Kirchhof, G., and So, H.B. 1995. Legumes after rainfed lowland rice. ACIAR Food Legume Newsletter No. 22. pp. 2-5.

Lantican, R.M. 1982. Desirable characteristics of upland crops for planting before and after wetland rice. *In* Cropping Systems Research in Asia. Report of a Workshop on Cropping Systems Research in Asia. IRRI The Philipp. Los Banos.

MnDonald, M.B., and Copeland, L.O. 1997. Seed Production: Principles and Practices. Chapman & Hall. New York.

McWilliam, J.R., and Dillon, J.L. 1987. Food legume crop improvement-progress and constraints. *In* Food Legume Improvement for Asian Farming Systems. Proc. of an International Workshop held in Khon Kaen, Tahiland, 1–5 September 1986.

Muslem Uddin Miah, M.D. 1991. The management of lowland clayey soils in Bangladesh for upland crops after rice. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

Nasr, H.M., and Selles, F. 1995. Seedling emergence as influenced by aggregate size, bulk density, and penetration resistance of the seedbed. *Soil and Tillage Research* 34, 61–76.

Nizami, M.I. 1991. The management of lowland clayey soils for upland crops after rice cultivation in Pakistan. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

Obcemea, W.N., Lucas, M.P., Pascua, S.R., Agustin, E.O., Marcos, T.F., Ladha, J.K., and Obien, S.R. 1996. Rainfed lowland rice-based cropping systems in the Philippines: A review. *In* G. Kirchhof, and H.B. So (Eds.). Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems. Proc. of a workshop held at the Bureau of Soil and Water management, Quezon City, Manila, 20–24 November 1995. ACIAR Proc. No. 70.

Pagliai, M., and Painuli, D.K. 1988. The physical properties of paddy soils and their effects on postrice cultivation for upland crops. *In* Soil Management for Sustainable Rice Production in the Tropics. Selected papers from the first International Symposium on Paddy Soil Fertility, Chiang Mai, Thailand 6–13 December 1988. International Board for Soil Res. and Manag., Monograph No. 2, Bangkok.

Palaniappan, S.P. 1991. The management of lowland clayey soils in Tamil Nadu for upland crops after rice. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

Pasandaran, E., Rusastra, I.W., Sudaryanto, T. 1992. Soybean development in Indonesia performance and constraints. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3-6, 1991. CGPRT Centre, Bogor.

Pasaribu, D., and McIntosh, J.L. 1986. Increasing tropical soybean production with improved cropping systems and management. *In* Soybean in tropical and Sub-tropical Cropping Systems. Proc. of a Symposium, Tsukuba, Japan. The Asian Vegetable Research and Development Centre. Shanhua.

Patanothai, A., and Ong, C.K. 1987. Limits imposed by management in rainfed farming systems. *In* E. S. Wallis, and D. E. Byth (Eds.). Food Legume Improvement for Asian Farming Systems. Proc. of an International Workshop held at Khon Kaen, Thailand, 1-5 September 1986. ACIAR Proc. No. 18.

Partley., J.E. and Corbin, E.J. 1994. Cultural practices. pp. 302–48. *In* J. Partley (Ed.). Principles of Field Crop Production. 3rd Edn. Oxford University Press: Melbourne.

Pushparajah, E., and Sompongse, D. 1991. Fertility and soil management considerations for a cropping system with upland crops after rice. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

Radjit, B.S. 1994. Mungbean package-technology invention for East Java. *In* . B.S. Radjit, Y.A. Betty, Sunardi, and A. Winarto (Eds.) Proc. of a Communication of Technology to Increase Food Crops Production in East Java. Indonesia Research Institute for Food Crops: Malang. (in Indonesian).

Sanchez, P. A. 1973. Puddling tropical rice soils: 2. Effects of water losses. *Soil Science* 115, 303–8.

Sanidad, W. B. 1996. Sowing technique for grain legumes planted after lowland rice in the Philippines. *In* G. Kirchhof, and H.B. So. (Eds.) Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems. Proc. of ACIAR International Workshop held at the Bureau of Soil and Water Management, Quezon City, Manila, 20-24 November 1995. ACIAR Proc. No. 70.

Sarobol, N., Uttayopas, A., Sewatasai, R., and Cnanaseni,C. 1992. Farmers' practices relating to soybean production technology and planting methods. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3-6, 1991. CGPRT Centre: Bogor.

Sharma, P.K., De Datta, S.K., and Redulla, C.A. 1988. Response of maize (*Zea mays* L.) and mungbean (*Vigna radiata* L.) to tillage in relation to water table depth in tropical lowland rice soils. *Soil and Tillage Research* 12, 65–79.

Smitobol, C. 1991. Production management techniques for soybean after rice in Thailand. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Research and Management, Proc. No. 11, Bangkok.

So, H.B. 1987. Soil physical factors limiting crop establishment. pp. 154-65. *In*. I.M. Wood, W.H. Hazard, and F.R. Form. (Eds.). Proc. of a Crop Establishment Workshop. Queensland Agricultural College, Lawes, 28–30th September 1987. Australian Institute of Agricultural Science, Occasional Publication No. 34.

So, H.B., and Ringrose-Voase, A.J. 1996. Management of clay soils for lowland rice-based cropping systems: An overview of ACIAR project 8938. *In* G. Kirchhof, and H.B. So. (Eds.). Management of Clay Soils for Rainfed Lowland Rice-based Cropping Systems. Proc. ACIAR International Workshop held at the Bureau of Soil and Water Management, Quezon City, Manila, 20–24 November 1995. ACIAR Proc. No. 70.

So, H.B., and Woodhead, T. 1987. Alleviation of soil physical limits to productivity of legumes in Asia. *In* E.S. Wallis, and D.E. Byth. (Eds.) Food Legume Improvement for Asian Farming Systems. Proc. of an International Workshop held at Khon Kaen, Thailand, 1–5 September 1986. ACIAR Proc. No. 18.

Sudjadi, M., Adiningsih, J.S., Rochayati, S., and Sofyan, A. 1991. Clayey soils for the cultivation of upland crops after rice in Indonesia. *In* The Management of Lowland Clayey Soils after Rice in Asia. International Board for Soil Res. and Manag. Proc. No. 11, Bangkok.

Suhartina. 2005. The Description of Released Varieties for Legumes and Tuber Crops. Indonesian Legumes and Tuber Crops Research Institute. Malang. 154 pp. (in Indonesian).

Sumarno. 1991. Production Technique for Food legumes and Coarse Grains in Indonesia. Paper presented at the Working Group's Planning and Consultative Meeting of RAS/89/040 Project. Regional Cooperative Program for Improvement of Food Legumes and Coarse in Asia. FAO-UNDP project. Chiang Mai, Thailand 29 July–3 August 1991. 9 p.

Sumarno and Adisarwanto, T. 1992. Soybean research to support soybean production in Indonesia. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia, 3–6 December 1991. CGPRT Centre, Indonesia: Bogor.

Sumarno, Oka, I.M., Sunarlim, N., Makarim, A.K., Sharma, D., Syam, M., and Manwan, I. 1988. National Coordinated Grain Legumes Research Program. Central Research Institute for Food Crops. Bogor. 64 p.

Suyamto., Sumarno., Fagi, A.M., and Suwardjo, H. (1989). Choice of crop and its management for planting following rice in puddled soils. Paper presented on 20th Asian Rice Farming System Working Group Meeting. Bogor 2–6 October 1989. 27 p.

Syarifuddin, A.K. 1982. Tillage practices and methods of seeding upland crops after wetland rice. *In* Cropping Systems Research in Asia. Report of a Workshop on Cropping Systems Research in Asia. IRRI The Philipp.: Los Banos.

Tisdall, J.M. 1996. Crop establishment-a serious limitation to high productivity. *Soil and Tillage Res.* 40, 1–2.

Townend, J., Mtakwa, P.W., Mullins, C.E., and Simmonds, L.P. 1996. Soil physical factors limiting establishment of sorghum and cowpea in two contrasting soil types in the semi-arid tropics. *Soil and Tillage Res.* 40, 89–106.

Trouse, A.C. Jr. 1971. Soil conditions as they affect plant establishment, root development and yield. A). Present knowledge and need for research. *In* K.K. Barnes, W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vanden Berg (Eds.). Compaction of Agric. Soils Am. Soc. of Agric. Engineers. Michigan.

Virakul, P. 1992. Economis returns on choices of input technology: An experience from SYGAP. *In* Priorities for Soybean Development in Asia. Proc. of a Workshop held in Bogor, Indonesia. December 3–6, 1991. CGPRT Centre: Bogor.

Wood, I.M., Wade, L.J., and So, H.B. 1992. Improving the establishment of grain sorghum in Australia: A review of research, development and extension activities 1989-1992. pp. 112-22. *In* M.A. Foale, R.G.

Henzell, and P.N. Vance (Eds.). Proc. second Australian Sorghum Conference, Gatton, 4 to 6 February 1992. Australian Inst. of Agric. Sci.: Melbourne, Occasional Public. No. 68.

Wood, I.M., and Myers, R.J.K. 1987. Food legumes in farming systems in the tropics and subtropics. *In* E. S. Wallis, and D. E. Byth (Eds.). Food Legume Improvement for Asian Farming Systems. Proc. of an International Workshop held at Khon Kaen, Thailand, 1–5 September 1986. ACIAR Proc. No. 18.

Zansdra, H.G. 1978. Soil management for rice-based cropping systems. *In* Soil and Rice. IRRI Phill.: Los Banos.

Zansdra, H.G. 1982. Effect of soil moisture and texture on the growth of upland crops after wetland rice. *In* Cropping Systems Research in Asia. Report of a Workshop on Cropping Systems Research in Asia. IRRI The Philipp. Los Banos.