PUDDLING AGAINST DRY PLOWING FOR LOWLAND RICE CULTURE IN SURINAM:

effect on soil and plant, and interactions with irrigation and nitrogen dressing

W. Scheltema

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Puddling against dry plowing for lowland rice culture in Surinam:

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Proefschrift
ter verkrijging van de graad van doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
prof.dr.ir. H.A. Leniger, hoogleraar in de technologie,
in het openbaar te verdedigen op woensdag 30 oktober des namiddags te vier uur
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Abstract

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The influence of tillage on rice grown on heavy Surinam clay soils was investigated in pot and field trials. Included were interactions with seed rate, nitrogen dressing and distribution, water management, and variety. Four procedures for tilled layer and seedbed preparation were studied morphologically, physically and chemically: wet, dry/wet, dry and zero.

Differences between tillage treatments were found in sedimented layers, fragmentation, moisture contents, bulk density, dehydration curves, amount of moisture extracted by suction, permeability, moisture potentials, structural stability, content of extractable ammonium, and iron and potassium concentrations in soil moisture. Plant growth and grain yield were influenced by tillage through seedling establishment and growth, nitrogen mineralization in the soil, recovery of applied nitrogen in the rice plant, total amount of applied nitrogen and its distribution, surface drainage, and mutual shading.

Shallow tillage, a few times in tilled layer preparation and a large wooden beam in seedbed preparation gave highest yields. The effect of the easiest procedures-- dry and dry/wet tillage--depended on the weather during the operation. The customary dry/wet tillage seemed harmful as it induced mutual shading thus reducing grain yield. Dry tillage was most beneficial to grain yield because of the high recovery of applied nitrogen. Wet tillage should be performed only when weather is unfavourable. Zero tillage is practicable, but weed control is troublesome.

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Stellingen

1
Modderen geeft in vergelijking met droge grondbewerking minder goede resultaten voor de gemechaniseerde rijstteelt op zware kleigronden in Suriname.

Dit proefschrift.

2
De door droge grondbewerking gestimuleerde sterke uitdroging van de bouwvoor vóór het aan de inzaai voorafgaande onderwaterzetten bevordert de groei en de opbrengst van rijst op zware organisch rijke kleigronden in Suriname.

Dit proefschrift.

3
Ammonium- of ureumstikstof, toegediend aan een tijdelijk drooggezet veld, wordt tijdens het opnieuw bevloeïen van het veld naar de gereduceerde bodemzone getransporteerd en is daardoor gevrijwaard tegen nitrificatie en daaropvolgende denitrificatie.

Dit proefschrift.

4
Bij het verkrijgen van een inzicht in de chemische samenstelling van het bodemvocht van gemodderde rijstgronden kan het gebruik van bodemvocht, onttrokken aan de grond in kluitstructuur in potten, aanleiding geven tot een vertekend beeld van de werkelijke situatie.

F.N. Ponnamperuma, Jaarverslag IRRI 1964-1971.

5
Bij ontginning van nieuw in cultuur te brengen gronden wordt te weinig gestreefd naar het instandhouden van een vaak gunstige fysische bodemgesteldheid.

6

De verplichting de stellingen behorende bij een proefschrift te onderwerpen aan de goedkeuring van de promotor is een vorm van verwerpelijke bevoogding en derhalve andragogisch onjuist.

7

Binnen organisaties zal zich een herwaardering van individuele capaciteiten voordoen, waarbij het vermogen om in samenwerking iets tot stand te brengen meer zal worden gewaardeerd dan het vermogen zelfstandig iets tot stand te brengen.

8

Er zou een wettelijke verplichting moeten komen voor stichtingen om binnen een korte termijn na oprichting in het bestuur voor tenminste de helft leden op te nemen die zijn afgevaardigd of aangewezen door medewerkers en door diegenen waarop de activiteiten van de stichting zijn gericht.

9

Het Nederlandse recht biedt onvoldoende mogelijkheden zich teweer te stellen tegen overmachtsposities van particuliere woningbeheerinstanties bij het stellen van voorwaarden aan huurders, zoals o.a. tot uiting komt in het eisen van uniforme naamplaatjes.

10

Het verplichten tot afvoeren van fietsen naar kelders en verafgelegen fietsenstallingen ter bescherming van het aanzicht van een gebouw, in tegenstelling tot het toelaten van auto's, getuigt van een overtrokken waardering van statussymbolen die vetaanzetting in de hand werkt.

11

Er moet veel gedaan worden, daarom gebeurt er weinig.

Proefschrift van W. Scheltema
Wageningen, 30 oktober 1974

Voorwoord

Dit proefschrift kwam in de afgelopen jaren tot stand op een wijze de bestudeerde zware, taaie, moeilijk hanteerbare klei van Suriname waardig. Het is onduidelijk, of daarbij de auteur de klei, dan wel de klei de auteur beïnvloed heeft, of dat er enig ander verband bestond.

In het gebeuren speelden zowel de Stichting voor de Ontwikkeling van de Machinale Landbouw in Suriname (die het werk mogelijk maakte) als de Landbouwhogeschool (die mij later als promotie-assistent aanstelde) een rol. Dit heeft ertoe geleid, dat een groot aantal personen en vele instellingen betrokken werden bij het onderzoek. Ergens daarin heeft de auteur zijn rol gespeeld.

De basis van het onderzoek werd gelegd door prof.dr.ir. L.J. Pons. Bij de uitvoering en het op schrift stellen ontving ik veel steun van dr. A. van Diest. Prof.ir. H. Kuipers en dr.ir. F.F.R. Koenigs hebben bij het kritisch doornemen van het manuscript mij geholpen.

Als pas afgestudeerde, luxueus genietend van een doos sigaren, vol van energie om nuttig aan de slag te gaan, begon ik in Suriname met een niemand en niets ontziende ijver te modderen. Het water werd daardoor eerst wel wat troebel, maar na bezinking begon het onderzoek op gang te komen, werden proefvelden aangelegd en medewerkers ingewerkt. In de loop van de jaren kreeg ik meer belangstelling voor omstandigheden buiten het onderzoek, met name voor de organisatie van het project 'Wageningen' en de mogelijke ontwikkeling ervan. Dit heeft mijn verdere loopbaan gericht op de samenwerking binnen organisaties.

Vele personen hebben zich, ieder op zijn manier, bezig gehouden met het totale gebeuren en ik wil de belangrijkste daarvan hier bedanken, in alfabetische volgorde.

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En de dames L. Dijkstra-Sepp, K. Scheltema-Boon en R. Wiebenga-Albers en de heer J. Bakker.

Levensloop

De auteur studeerde tropische cultuurtechniek aan de Landbouwhogeschool in Wageningen. Na het behalen van zijn ingenieurs diploma in 1966 werkte hij bij de Stichting voor de Ontwikkeling van de Machinale Landbouw in Suriname en later ook voor de Landbouwhogeschool. Hij onderzocht de invloed van verschillende wijzen van grondbewerking op de grond en de plant en de daaruit resulterende rijstopbrengst. De organisatie van het Wageningen project in Suriname met zijn samenwerkings aspecten en aanpassingen aan veranderende situaties daagden hem uit. In 1971 keerde hij terug naar Nederland, waarna dit proefschrift tot stand kwam. Ondertussen bekwaamde hij zich in organisatie ontwikkeling en als begeleider van groepen, waarin hij een nieuwe werkkring heeft gevonden.

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1 Introduction

1.1 OBJECTIVE, MODEL AND AREA

The *objective* of this study was to investigate the growth and yield of rice on heavy soils in Surinam, as affected by 4 tillage methods. The result should contribute in various practical situations to decisions about tillage method and about crop management (seed rate, water management, nitogen fertilizer) for each tillage method. The discrepancy between data from the literature and local experience on the effects of puddling also needed clarification.

The *model* of the subject matter is presented in a scheme (Fig. 1) showing two approaches (Kuipers, 1963). The first approach occupies the upper half of the figure and compares the returns and costs. In my study only direct costs will be dealt with.

The second approach in the lower half of the figure is the path, along which tillage influences grain yield. Tillage is seen as part of the land preparation between two crops. The other parts of land preparation, stubble treatment and field trenching, are described but not analysed.

Tillage influences soil structure, which has been investigated physically and morphologically. The physical properties influence in turn, the chemical and biological properties of the soil. Biological properties were not considered separately in this study, though most chemical soil components dealt with, originate from microbial activity.

The interaction between tillage, water management and nitrogen fertilization will be treated separately. I also studied plant growth as influenced by physical and chemical changes caused by tillage. The relations between nitrogen dressing, tillage, plant growth and grain yield are studied by different trials.

The *area* was part of the young coastal plain of Surinam with very heavy clay soil: the Wageningen Polder reclaimed 20 years ago.

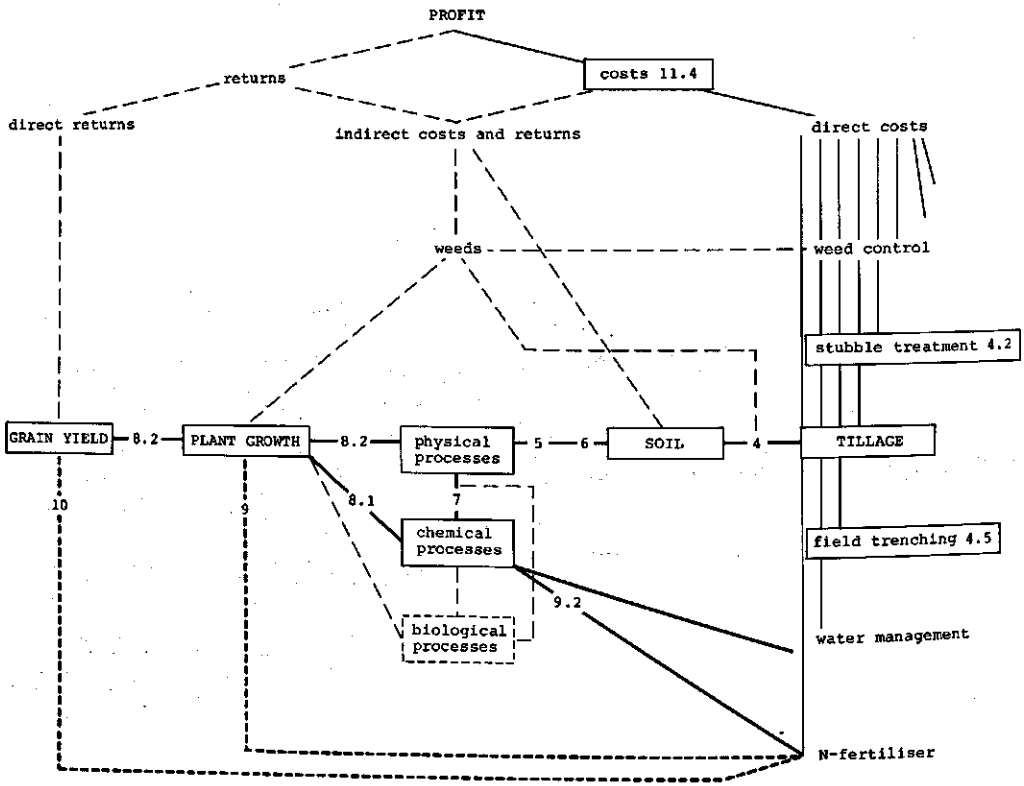

Figure 1. Model indicating the subjects investigated and the corresponding sections.

This study was made possible by the Foundation for Development of Mechanized Agriculture in Surinam in cooperation with the Agricultural University at Wageningen, Netherlands.

1.2 SOIL TILLAGE IN LOWLAND RICE CULTIVATION

In Asia, tillage of wet or inundated soils ('puddling') has, for millennia, played a dominating role in continuous rice cultivation. It had, and still has, many advantages over dry tillage in loosening the soil for the preparation of the seedbed, and is generally said to have only a few drawbacks.

1.2.1 Advantages and disadvantages of puddling in traditional rice production

The advantages of puddling were of major importance:

(1) Tillage when the soil is flooded is much easier than when it is dry, especially because rice cultivation is usually concentrated on heavy soils whereas lighter soils are used mainly for other crops. No strong tools are needed; those of wood last long as abrasion is slight and brakages are few. Traction is no limiting factor: one man or one animal can be sufficient. They even contribute to the tillage process by moving around.

(2) A wet puddled soil makes it simple to transplant rice plants from the nursery with little injury, while optimum use of the available land and seed, is made.

(3) Soil preparation can be delayed till the rainy season starts, which also guarantees sufficient water for the young stand. Except with puddling, weeds easily become reestablished when the still dry soil is tilled (and are then hard to combat when the rains start).

(4) Continuous rice cropping may result in an unsurmountable weed problem; the puddling system, combined with previous flooding before planting and during crop growth, avoids this.

(5) Puddling establishes a less permeable layer in the soil and prevents high water loss by seepage. Such losses are dangerous mainly where only a limited supply of irrigation water is available.

(6) Puddling itself may remove, to a certain extent, the unevenness of the soil surface. Greater differences in height of the surface can easily be corrected under water with simple implements.

The disadvantages of puddling are usually considered to be of minor importance.

Indeed it is troublesome to work in a wet field, both for man, and animal but this trouble is not important as long as available land, water, seed and animal traction are more limiting than manpower.

1.2.2 Present situation

In Asia, where puddling is still widely practised in rice production, the introduction of tractors and of stronger tools has allowed clod-making on the dry soil. After this dry tillage a wet tillage is performed, involving one or more puddling treatments.

In North and South America, however, the situation is often different: heavy machinery is used on the large farms only for dry plowing. Puddling and even tillage of moist soil are avoided as much as possible. One of the reasons is that in many rice-producing areas there (United States, Mexico, Colombia, Peru) the climate is characterized by long periods of low rainfall, so that most of the irrigation water has to be transported from catchment areas outside the growing region. Only where high rainfall throughout the year prevents a thorough drying of the soil, dry tillage is impossible. This does not apply to the Guyanas where, puddling is still customary on small farms and executed on larger farms when weather conditions are unfavourable.

The advantages of puddling disappear or change into disadvantages in mechanized rice farming on heavy clay soils in Surinam. The advantages (p. 3) of puddling in the traditional rice production system will be re-examined therefore with reference to the Wageningen Polder:

1 The high power of tractors allows dry plowing with few repetitions. The strength of the tools is not longer a limiting factor.

2 Transplanting was abandoned as labour is relatively expensive while sufficient seed and land is available. It has been replaced by sowing soaked rice seeds distributed by hand or from a plane.

3 Adjusting the time of tillage to rainfall had to be replaced by an irrigation system allowing double cropping based on a more rigid time schedule.

4 Post sowing weed control, if needed, has become possible by applying chemicals and is therefore less dependent on tillage.

5 In the Wageningen Polder, it is not necessary to reduce water losses by seepage: the permeability of the heavy clay is so low that water movement through the profile is severely restricted.

6 It remains possible to level the soil by puddling (or this even occurs automatically) as long as the surface is not too uneven.

Larger areas with greater differences can be levelled with special tools, on dry soils only, to avoid local drowning of seeds in soft mud and sinkage of combines and machines into the subsoil.

Doubtless the use of machines on a flooded field has its disadvantages. The maintenance costs of the machines are high and their use during tillage is rather troublesome. The machines may get stuck in the unripened subsoil, especially when the fields are kept too long under water in a double-cropping system without adequate periods of partial drying (which increases the bearing capacity of the top soil).

In rice cultivation, tillage is nearly always associated with puddling soils. To plow when the soil is still dry is a method introduced only relatively recently in the history of lowland rice cultivation. Though in Surinam it results in higher grain yields, this is not in accordance with most literature available on this subject.

1.2.3 Tillage in Surinam

Rice was introduced in Surinam by immigrants from India and Indonesia, together with the practice of its cultivation which included puddling. This process was first carried out by hand and feet. Afterwards, oxen were introduced as draught animals, and in the 1930s the use of tractors started. Nowadays, in the more advanced rice-growing district of Nickerie, almost all ricelands are tilled with the aid of such machines.

Originally, one crop was cultivated each year, followed by a fallow period in which the field was surface-drained to allow dry plowing after drying of the soil. It lasted until the 1970s before double cropping (two harvests a year) became popular. The examples in the Nickerie district, and its start on some large rice estates, also induced farmers elsewhere to switch to this method. Because of unstable weather puddling is often still necessary on soils not sufficiently dried.

In general, dry tillage is considered superior to puddling because it results in higher yields (Fortanier, 1962; Hasselbach et al., 1965; ten Have, 1967), though the reverse may occur. Those authors assume that the deterioration of soil structure by puddling, depresses grain yields, through stimulation of soil reduction.

Elsewhere, several papers reviewed by Sanchez (1968) have compared the influence of mud and clod structure on the growth of rice. With the exception of Dei et al. (1973), they all conclude that mud is at least equivalent to a clod structure for rice production.

The inconsistency of the beneficial effect on grain yield of dry plowing, the discrepancy of this effect with literature and the frequent uncertainty of obtaining this effect were associated with unfavourable weather.

Recently the view that for proper crop growth, soil tillage is a necessity, has been challenged. These considerations resulted in trials in which zero tillage treatments were included.

1.3 GENERAL DATA OF SURINAM

Surinam belongs to the Guyanas located on the north-east coast of South America. Surinam is situated between Guyana and French Guyana (Fr.Quiana). On the south it borders Brazil (fig. 2).

Geomorphologically six-sevenths of Surinam is covered by residual soils. But northwards are the Zanderij formation, and then the old and the young coastal plain running parallel to the coast.

Rice production in Surinam is concentrated in the young coastal plain. This plain consists of Holocene sediments of the Coroni deposits (Brinkman, 1968), originating from the Amazon region transported along the coast by the Guyana stream (Reyne, 1961).

The Wageningen scheme is in east Surinam in the Nickerie District. Together with the other rice polders in this district, it is situated on soils of the Moleson phase (2500 to 1300 BP) of the Coroni deposits in the young coastal plain. The sediments occur at the present high-tide level: they have a high base saturation and the process of desalinization has not gone deeper than 100 to 150 cm. The lowest parts of this sediment are unmottled, are only partly ripened and are impermeable.

The *soils* consist mainly of very heavy clays, in which the sand fraction is almost absent (Table 1). The mineralogical composition of the clay fraction

Table 1. Average particle-size distribution of soils in the Wageningen Polder

Fractions		Depth (cm)				
		0-20	20-40	60-80	120-140	180-200
< 2 µm,	in %	82	73	69	71	75
2-20 µm,	in %	27	26	29	29	25
20-50 µm,	in %	0.6	1.5	1.7	0.0	0.0
> 50 µm,	in %	0.2	0.1	0.2	0.1	0.2

is about 20% inactive silica, 40% kaolinite, 20% illite and 20% montmorrillonite and chlorite (Brinkman, 1960).

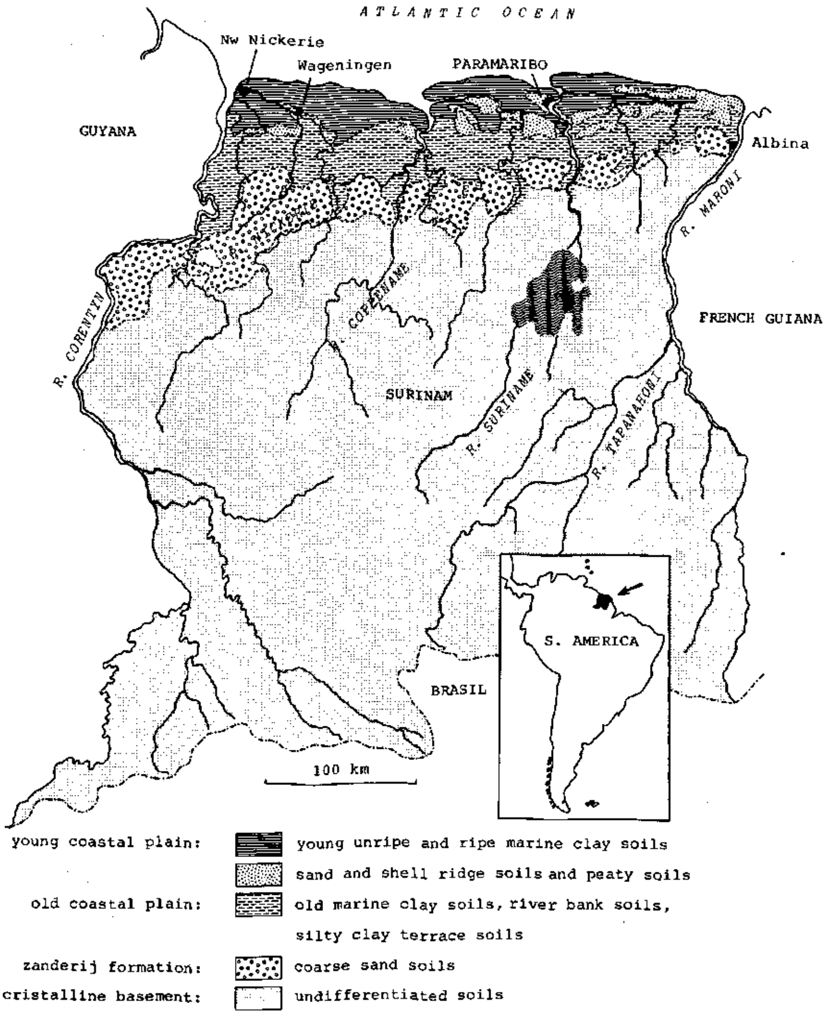

Figure 2. Surinam and its main soils.

Some chemical data on soils in the Wageningen Polder are given in Table 2 and 3. These data refer to the soils of the "Experimental Field 4th reeks", which is in the centre of the polder, where most field trials were carried out. The magnesium occupation of the absorption complex is higher than that of calcium. But a negative influence on mechanical soil structure stability is not expected (Scheltema, 1965).

The Wageningen Polder has been reclaimed out of a swamp forest and herbaceous swamps. The reclamation started in 1951. Detailed information of the reclamation is given by de Wit (1960). From north to south in the Wageningen Polder the desalinization of the marine sediments decreases. Almost parallel to the decreased desalinization the physical ripening has been less intense. As the clay contents are equal, moisture contents are given in Table 4.

Table 2. Composition of cation-exchange complex of soils in the Wageningen Polder (after Kamerling, 1974).

mmol per 100 g dry soil	Depth (cm)				
	0-12	12-22	35-45	60-90	100-150
Na	1.9	3.4	3.7	3.8	4.6
K	0.6	0.7	0.9	1.0	1.7
½ Mg	18.7	19.7	17.7	14.8	14.7
½ Ca	9.7	10.1	9.1	8.1	10.0

Table 3. Some chemical data on the upper soil layers in the Wageningen Polder.

Depth (cm)	Ca (mg/litre)[2]	Mg	K	NH_4	NO_3	Fe	Al	Mn	SO_4	Cl
0-10										
20-40	765	715	23	10.0	10.0	167	63	12	17	30
40-60	705	813	40	6.8	4.5	80	34	9	9	178

	% org. matter	% N	pH-KCl	% Fe_2O_3 in 10% HCl[1]
0-10	7.2	0.35	4.3	4.5

1.After Dirven, 1967.
2.Based on the Morgan-Venema extraction (R.Neth.Trop.Inst., Amsterdam)

Table 4. Soil salinity and soil moisture in extreme parts of the Wageningen Polder.

NaCl in dry soil (g/100 g)			Moisture as % (w/w)		
depth (cm)	south	north	depth (cm)	south	north
10	0.04	0.18	25-50	53	77
50	0.15	0.46	50-75	56	82
100	0.24	0.60	75-100	56	85

South/north refers to sites in the southern and northern parts of the Wageningen Polder, the latter closer to the sea.

The soils of the Wageningen Polder are mapped by van der Broek (1968). Two soil descriptions from the author and others of representative areas of the polder are given: one representative for the southern part and one for the northern part.

PROFILE: WAGENINGEN POLDER, NORTH (reeks 8, perceel 493)

Described by S. Slager, W. Scheltema and G. Kamerling (12-4-1967) near end of short dry season in which evaporation had exceeded rainfall.

Fluventic Hydraquentic Tropaquent (7th Approximation with amendments, 1967).

Climate: according to data for Nieuw Nickerie Meteorological Station (Table 7).

Geology: heavily textured holocene marine deposits (Demarara clay)
Physiography: centre of swamp
Alt. 0.9 m + NSP
Slope, relief and microrelief: flat
Stoniness: class 0
Depth of undisturbed subsoil: > 2 m
Hydrology: poorly drained; groundwater table at 125 cm, presumed lowest at 150 cm, highest above surface: flooded twice a year for about 200 days artificially drained
Biological activity: few to no roots, few to many very fine to fine biopores in peds, few on ped faces, depth of undisturbed subsoil: > 2 m
Land-use: 16 years rice

Soil description

Ap (g)	0- 15 cm	very dark to dark-gray (7.5YR 3.5/2) when dry; clay; strong very coarse prismatic with few very fine biopores; very hard; common fine faint brownish-yellow (10YR 6/8) iron mottles concentrated on ped faces; pH (Hellige) 6.5; abrupt wavy boundary.
B1g	15- 35 cm	gray (N5/0) in peds, light-gray to gray (N6/0) on ped faces when moist; clay; moderate coarse prismatic, very sticky and plastic; abundant, medium distinct brownish-yellow to yellowish-brown (10YR 5.5/6) iron mottles; pH (Hellige) 7.0; clear, smooth boundary.
B2g	35- 80 cm	light-gray to gray (N6/0) when wet; clay; moderate, medium smooth prismatic, with many stress cutans and few to many very fine to fine biopores in peds, common large biopores; very sticky and plastic; common large distinct yellowish-brown (10YR 5/8) iron mottles, mostly concentrated along root holes; pH (Hellige) 8.0; diffuse and smooth boundary.

B3g	80-125 cm+	gray (N5/0) when wet; clay; hole structure with common stress cutans; many large biopores and common to few very fine to fine biopores on ped surfaces; very sticky and plastic; common medium prominent yellowish-brown (10YR 5/8) iron pipes especially along root holes; pH (Hellige) 8.0.

Detailed description of soil structure (after Jongerius, 1957):

0- 15 cm	Ap (g)	B5a	V	3		
15- 35 cm	B1g	B5a	IV	2		
35- 80 cm	B2g	B5c	III	2	20-50%	sc
80-125 cm	B3g	G3b			10%	sc

Data on occurrence of biopores are given in Table 5.

Table 5. Distribution of numbers of biopores in the Wageningen South profile.

Depth (cm)	Size and position				
	fine (< 2 mm/cm^2) in peds		fine (< 2 mm/cm^2) on ped faces		large (> 2 mm/dm^2)
	individual values	mean values	individual values	mean values	range
10			6-4-1-3-7	4.2	
20			3-5-3-1-7	3.8	
30	16-9-11-6-14	11.2	7-2-11-7-2	5.8	
40	8-7-15-12-10	10.4	6-5-2-2-2	3.4	
50	7-8-6-4-5	6.0	1-4-3-5-0	2.6	
60	3-5-4-6-4	4.4	2-0-1-0-1	0.8	0-5
70	5-6-8-9-4	6.4	2-3-4-2-3	2.8	0-5
80	1-3-6-6-7	4.6	2-4-4-1-2	2.6	0-5
90			5-3-5-6-7	5.2	5-10
100			2-4-1-3-5	3.0	5-10

PROFILE: WAGENINGEN POLDER, NORTH (reeks 8, perceel 493)

Described by S. Slager, W. Scheltema and G, Kamerling (11-4-1967) near end of short dry season in which evapotranspiration exceeded rainfall.

Fluventic Hydraquentic Tropaquent (7th Approximation, 1967)

Climate: according to data for Nieuw Nickerie Meteorological Station (Table 7)

Geology: heavily textured holocene marine deposits (Demarara clays)
Physiography: swamp center
Alt. 0.80 m + NSP
Slope, relief and microrelief: flat
Stoniness: class 0
Hydrology: poorly drained; groundwater table below 100 cm, presumed lowest at 150 cm, presumed highest about 15 cm above soil surface: flooded about 200 days, artificially drained
Biological activity: few or no roots, few to common very fine to fine and abundant large biopores; depth of undisturbed subsoil: > 2 m
Land-use: 6 years rice

Soil description

Ap 0- 10 cm	black (10YR 2/1) when moist; clay with common organic matter, moderate fine cloddy subangular blocky with few very fine to fine biopores; firm; pH (Hellige) 6.0; clear and smooth boundary
B1g 10- 18 cm	light-gray to grayish-brown (2.5Y 6/1) when moist; clay; strong, very coarse compound prismatic subdivided into weak very fine angular blocky with coatings of loose organic matter on ped faces and few very fine to fine biopores; sticky, non-plastic; common fine distinct strong-brown (7.5YR 5/6) iron mottles; pH (Hellige) 6.5; gradual and smooth boundary
B2.1g 18-40/55 cm	light-gray to gray (5GY 6/1) when moist; clay; strong, very coarse compound prismatic, subdivided into weak very fine angular blocky and moderate to weak very coarse prismatic with coatings of loose organic matter on ped faces and few to common very fine to fine biopores; very sticky, very plastic; many medium prominent strong brown (7.5YR 5/6) iron mottles; pH (Hellige) 8.0; diffuse and wavy boundary

B2.2g 40/55- 73 cm	light-gray to gray (5GY 6/1) when moist; clay; moderate to weak very coarse prismatic with common very fine to fine and abundant large biopores; very sticky, very plastic; abundant large faint strong brown (7.5YR 5/6) iron and manganese, and few fine faint dark-brown to brown (7.5YR 4/4) iron mottles; pH (Hellige) 8.5; diffuse and smooth boundary
B3g 73-117 cm	gray (5Y 5/1) when moist; clay; moderate to weak coarse rough prismatic with common to few very fine to fine and abundant to many large biopores; very sticky, very plastic; many fine distinct pale-olive to olive (5Y 6/3) iron mottles along root channels; few to common medium distinct siltballs with iron; pH (Hellige) 8.5

Detailed description of soil structure (after Jongerius, 1957):

0- 10 cm	Ap	S A4	IV	1 1/2		
10- 40 cm	B1g + B2.1g	B3a	VI	3/A5	III	1/2
40-100 cm	B2.1g + B2.2g + B3g	B5a	V	0		

Data on the occurrence of biopores are given in Table 6.

Table 6. Distribution of numbers of biopores in the Wageningen North profile.

Depth (cm)	Size and location		
	fine (< 2 mm/cm^2) in peds		large (> 2 mm/dm^2)
	individual values	average values	range
10			
20	2-2-1-5-4	2.8	
30	4-4-6-7-7	5.6	
40	2-7-7-5-4	5.0	
50	5-7-4-5-6	5.4	10-15
60	4-5-2-4-6	4.2	10-15
70	7-8-6-4-4	5.8	10-15
80	5-7-3-3-3	4.2	10-15
90	3-1-2-3-2	2.2	10-15
100	3-3-2-3-3	2.8	5-10

The *climate* is summarized by meteorological data of Nieuw Nickerie in Table 7. Nw.Nickerie is a 30 km from the Wageningen Polder, and its data are representative.

The major variation in weather throughout the year is the distribution of rainfall. Four seasons are distinguished on basis of the frequency of monthly rainfall (Fig. 3).

long wet seasons: from April till August
long dry season: from September till November
short wet season: from December till January
short dry season: from February till April

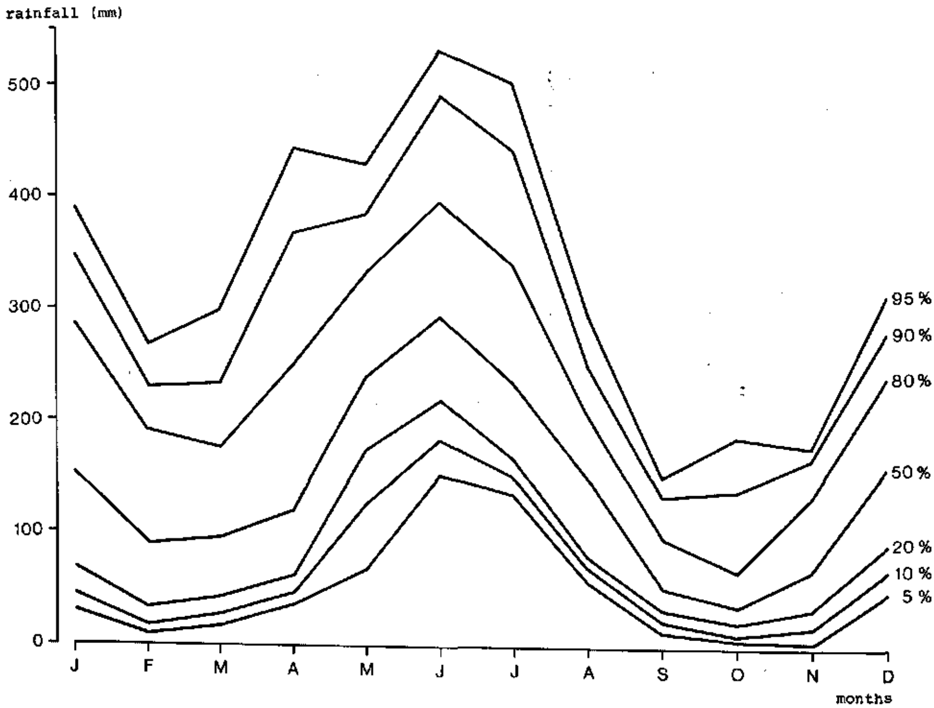

Figure 3. Curves indicating probability of less rainfall than the amount on the ordinate, calculated over the period 1907-1952 (after Krass, 1953).

Table 7. Average meteorological data for New Nickerie, 05°57'N, 57°02'W (1931-1960

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Temperatures:													
abs.min	18.3	18.2	19.1	19.9	20.7	20.6	20.9	19.9	20.9	20.3	20.0	20.1	18.2
av.minimum	23.5	23.7	24.0	24.2	24.2	23.9	23.7	24.0	24.2	24.0	23.9	23.7	23.9
average °C	26.5	26.6	26.9	27.2	27.2	27.1	27.2	27.8	28.3	28.2	27.8	27.0	27.3
av.maximum	28.9	29.0	29.2	29.5	29.8	29.8	30.3	31.1	31.7	31.7	30.9	29.8	30.1
abs.max.	32.5	32.4	32.5	33.2	34.8	34.0	34.5	35.6	35.4	36.3	34.9	33.8	36.3
relative hymidity %	82	81	80	80	82	83	82	80	78	78	79	82	80
cloudiness %	61	60	59	62	64	60	56	53	50	52	56	61	58
sunshine %	50	55	56	55	48	53	63	70	78	73	66	52	60
rainfall, mm:													
average	190	114	111	191	246	316	266	168	61	62	79	176	1978
max. in 24h	116	82	141	202	167	217	136	80	75	93	89	116	201
Av. wind velocity[1]	1.8	1.9	2.0	2.0	1.7	1.4	1.3	1.4	1.6	1.7	1.7	1.7	1.7
Prevailing wind at:													
0800	E	E	ENE	E	E	SE	SE	SE	ESE	ESE	ESE	SE	E
1400	NE	NE	NE	NE	ENE	NE	NE	NE	NE	NE	NE	NE	NE
1800	ENE	ENE	ENE	ENE	E	E	E	E	E	E	E	E	E

[1] Beaufort scale.

The long dry and wet season occur rather regularly. The short wet season is sometimes absent, the long dry season then extends to the next long wet season. But the short dry season is rather wet if there is a short wet season.

Within the Wageningen area there are slight differences in annual rainfall: a general decrease in precipitation with decreasing distance to the coast. In the south of the polder, the average annual rainfall is 1900 mm; in the north it is 1600 mm. The number of sunshine hours increases nearer to the coast proportional to the decrease in rainfall.

1.4 LOWLAND RICE PRODUCTION IN SURINAM

There are three types of rice farms in Surinam:

(1) Small farms (0.1-2 ha) on which young plants are reared on special beds and are transplanted to the puddled field and on which machines are not used or are limited to tillage. This type of farming is practised in the central and eastern part of the coastal plain in the Districts Coroni, Saramacca, Paramaribo, and Commewyne, where the quantity of irrigation water is limited or drainage is poor.

(2) Medium farms (1-30 ha) with direct seeding, mechanized tillage and harvesting, top fertilization with nitrogen, and limited chemical weed and insect control. This method is practised in the Nickerie District only. It needs an irrigation and drainage system.

(3) Large farms (100-10.000 ha) with highly mechanized (plane) direct seeding, fertilization and intensive chemical weeds and insect control. Heavy equipment and tractors are used for tillage, trenching and harvesting. The well developed irrigation and drainage system is facilitated with a fixed tertiary part and the use of pumping installations in the primary part of this system. This type of farming is found in the Nickerie district and in some other parts of the coastal plain.

The following discusses only large-scale farming, as used in the Wageningen scheme, but most of it also applied to the medium farms. For details on small-scale farming see Hasselbach (1965, 1966), Ubels (1964).

1.5 CROP MANAGEMENT OF LOWLAND RICE IN THE WAGENINGEN SCHEME

Extensive information on history, land reclamation, varietal breeding and cultural practices in the Wageningen Polder is given by de Wit (1960), Fortanier (1962), ten Have (1967), van der Broek (1969), Overwater (1960, 1971), de Boer (1971) and van Dijk (1971). Here only the present situation will be discussed.

Large-scale farming requires a rigid planning for the preparation of the seedbed, seeding, water management, harvesting and various additional activities (see Table 8).

In the Wageningen rice polder, planes play an important role in sowing and in application of fertilizer, weedkillers and pesticides. Only with the use of planes is it possible to deal with heavy infestations of insects in the monocultured area of 9000 ha, surrounded by swamps. Their application excludes the necessity to enter the field with machines in the period between tillage and harvest, which may cause considerable harm to the crop and dams.

Traffic over the soil is absent during the growing season (Table 8). No compaction due to machine operations exists after seeding. Soil traffic is limited to combine-harvesting, stubble treatment and tillage.

Two special circumstances in the Wageningen scheme affect rice crop management: (1) the large scale heavy mechanized farming and (2) the absence of limpid irrigation water. They will be dealt throughout this section.

Land preparation practices dealing with stubble treatment, soil tillage and trenching will be dealt with in Chapter 4. In the following sections those crop management aspects related to tillage treatments or interfering with their effects on crop growth are discussed.

1.5.1 Seeding

Seeding on a dry soil with emergence depending on rainfall does not fit in the rigid planning. The use of dry seed on a wetted soil gives the young plants no lead over the weed plants, as their emergence start together, necessary to effectuate chemical weed control. Pre-soaked seed is therefore used.

To avoid a layer of dirty water, in which young rice plants do not develop well, the fields must be surface drained for some time after seeding (though the soil has to be kep moist, otherwise the plants will dry out). This would not be necessary if sufficient limpid irrigation water was available, but the water of the Nickerie river contains so much silt (partly due to the stagnation in its discharge by the tides in the long dry season) that

Table 8. Course of land preparation and crop management activities (in brackets:optional)

		Traffic over soil	Planes for application of	Water management	Manual labour
Land preparation	1	stubble treatment			
	2				burning stubble and straw left by combine
	3	tilled preparation		inundation	
	4	seedbed preparation		inundation	
	5			inundation	
Crop management	6		snail pesticide		
	7	mechanical trenching			
	8		seeding	drainage	
	9				digging for surface drainage
	10		(caterpillar pesticide)		
	11		(monocotyledons weedkiller)		
	12			inundation	
	13				removal of red rice
	14			drainage	
	15		1st nitrogen fertilization		
	16			inundation	
	17			partial drainage	
	18		(dicotyledons weedkiller)		
	19			inundation	
	20			drainage	
	21		2nd nitrogen fertilization		
	22			inundation	
	23			drainage	
	24		3rd nitrogen fertilization		
	25			inundation	
	26		4th nitrogen fertilization		
	27		bug pesticide		
	28				removal of red rice
	29			drainage	
	30				digging for surface drainage
	31	harvest			
start again with 1					

it is suitable[1]. Here the advantage of using soaked seed is obvious.

The amount of seed ranges from 80 to 120 kg/ha, according to the variety and the properties of the seedbed. When locally many plant residues are present, or some pools are present where emergence is expected to be too low, an increased seed rate does not necessarily result in a better stand: the abnormal spots may not profit and on favourable places plant density may become too high.

Before sowing, the rice seeds are soaked for 24 h in water and afterwards kept moist for 24 h when seed-bed conditions are favourable, for 36 h when they are unfavourable. The seed is sown in a layer of water mostly. This water layer avoids sinking of the seeds too far into a soft, puddled soil, otherwise the growth of the rice seedling would be retarded and lose its advantage over weed seedlings. When the surface of the soil is covered with to many plant debris, the seeds may dry out so that drainage of the field has to be postponed. When unevennes of the field results in pools, flattening or trenching on a drained field may be necessary before seeding. The seed is then sown on a drained field.

1.5.2 Weed control

Stubble treatment only slightly influences weed growth. Though the aerial parts of the plants are attacked, most of their seeds have already dropped and many species will form new sprouts from their subterranean parts. The preparation of the tilled layer, and especially the drying of the soil after clod formation, destroys the pernicious weeds. Puddling and continued inundation cause the plant parts to rot, but only prolonged inundation largely destroys pernicious weeds.

The last mechanical control of weeds is during seedbed preparation. It attacks only those weeds that have emerged after the preceding tillage. Light puddling covers them with a thin mud layer.

If flooding could be continued after seeding, special weed control measures would be superfluous at this stage. Circumstances, however, enforce subsequently a two weeks' drainage period. They are: the muddy irrigation

1. Even if the river water were suitable, the long transport through the canal between river and Wageningen Polder, while this canal also serves drainage, would make it so.

water, the deposition of mud by diatoms on seedling leaves, and the infestation of irrigation water with the rice weevil *Helodytes* and snails.

Muddy irrigation water severely retards seed emergence and seedling growth (ten Have, 1967) because it decreases photosynthesis. Diatoms deposit mud on the rice seedlings, with the same effect, and during drainage intervals or changes in water level, they cause the leaves of the plants to stick to the soil so that growth may even stop entirely.

Helodytes attacks young seedlings. The animals readily spread through the reuse of the drainage water for irrigation purposes. In a few days they can destory hectares.

Drainage after sowing starts regrowth of weeds and the germination of dormant seeds. The soaked rice seeds get a lead of 2-3 days to overcome the threatening competition with the weeds. Afterwards monocots seedlings in the 2-3 leaf-stage can be effectively treated with pesticides not damaging the rice plants too much (with propanil) if they are already 10-14 days old. Heavy infestations of dicotyledons are attacked with 2-4-D in the 4th week after seeding.

A delay of drainage after seeding slows down weed emergence. This is most obvious after dry and zero tillage, where the weed seeds are not covered by a sedimented layer. With dry tillage, the surface area of the soil is largely increased, promoting germination of weeds and their development so that the rice plants lose their favourable lead position. Under such circumstances, chemical weed-killers must be more carefully timed.

After puddling, most weeds are incorporated in the mud. Their growth stops, but as a rule they are not killed by an inundation period of three weeks or less: then growth starts again and it becomes difficult to attack them with chemicals. The emergence of weed seeds is strongly retarded, after puddling as they are covered by a sedimented layer and to attack them with chemicals remains rather easy.

With zero tillage, weed control is possible only by means of herbicides and flooding. On fields infected with weeds sprouting from their roots, zero tillage is impossible. After stubble treatment, weed growth can be avoided by flooding the field till the moment it is sown. A special treatment schematized in Fig. 9 is wetting of the soil after stubble treatment to promote weed emergence, after which weed growth is stimulated by surface drainage. At their susceptible growth stage (2-3 leaves), they are sprayed with chemicals. Then the field is flooded deep until seeding.

If the field is already heavy infected with weed plants, a more rigorous use of chemicals is needed, as they are less effective and less workable, in the older growth stages of the weeds.

1.5.3 Water management (Table 8)

Irrigation and drainage system. Drainage and irrigation systems are separated. The fields (12-71 ha) have a system of parallel ditches at distances of 100-200 m, are 600 m long, with a capacity of 0.5 m^3 per m length. They are connected with the drainage and the irrigation canals by closable tubes. All water movement is based on gravity flow, as the subsoil (at 20-50 cm) is almost impermeable. The capacity of the system is such that the fields can be flooded and drained in 24-48 hours.

To facilitate surface water movement, trenches are dug every season with the trench-wheel (4.5) before seeding, and by shovelling afterwards. The fields are levelled to within about 5-15 cm.

Intercrop period. Fig. 9 shows the course of water management during the intercrop period. Water management during the intercrop period depends on tillage. Here it is sufficient to remark that this water management governs the time available for tillage especially at dry plowing. The harvest dates have to be fixed in accordance with the two dry seasons. The time needed for drying the soil, and precipitation, govern the tillage system. These aspects will be dealt with in 4.6.

Pre-seeding flooding. It takes 24-48 hours to flood the soil. The snails hiding in the moist subsoil, need at least a day to reach the surface after inundation. There they are killed with a pesticide (sodium pentachlorophenol: 2-5 kg/ha) which is also used in large quantities to kill weeds (it interfers with photosynthesis). To avoid damage to the rice seed, this unstable compound has to be applied 3-5 days before seeding. In total the period of flooding last at least 7 days, at dry/wet tillage this period also includes seedbed preparation.

Post-seeding drainage. The drainage starts in the period from one day before to two days after seeding. The time of drainage depends on weed control measures, and on weather conditions. The soaked seeds, whose root tip have already emerged, must touch the moist soil or water to stay alive. After surface drainage, cloudy weather or one or more showers of several millimeters allow the young plants to establish themselves, but a few windy and sunny days may result in a too high evaporation retarding establishment or causing the death of the young plants.

With zero tillage the topsoil quickly dries, and water supply soon becomes insufficient. The presence of plant debris on the soil surface is fatal for seeds lying upon them in these circumstances. The chances of failure are considerable, especially where some plant debris remain after burning (8.2).

After plowing, the quickly drying tops of the clods form a nother source of failure, though sufficient open water spots between the clods remain available.

Flushing. If evapotranspiration is high, flushing the fields during the post-seeding drainage period is necessary. If so, seedling establishment is difficult with zero tillage: the surface is rather flat so that small water pools are absent, little water is present in the top layer of the soil, and water supply from below is very low.

After puddling, the quantity of available water is high in the top centimeters. The roots of the seedlings have penetrated the soil and the plants have settled before heavy cracks occur.

After dry tillage, drought kills most seedlings on top of the clods, but the quantity of water in the tilled layer is so high (all interclod pores are filled and serve as reservoirs) that the growing seedlings are regularly spread over the surface, though their establishment percentage is somewhat lower (8.2).

In extremely dry periods, flushing is needed in all tillage treatments. According to the depth of the desiccated top layer and on field size, it then takes 24-48 hours. During this procedure seedlings can be damaged by sedimentation of mud on the leaves, and attacks by snails and water weevils *(Herodytes)*. This has to be accepted, as without flushing the damage will be greater. Fortunately damage caused by flushing is mostly only local and is concentrated on low spots in the field.

Inundation during crop growth. After post-seeding drainage, the ricefield is flooded till two weeks before harvest. This is mainly necessary for weed control. During crop growth, however, intermediate periods with drainage of the surface are needed to facilitate weed and algal control and fertilizer application (Fig. 9).

Flooding is 10-144 days after seeding, one day after the application of chemicals against monocotyledon (if necessary). The water level is raised as high as possible to submerge the weeds, but the tops of the rice seedlings have to remain above the water. During the following weeks (till 45-50 days after seeding) the rise has to keep step with seedling growth to retard weed growth and without too much retarding of tillering.

Afterwards a deep water level causes excessive elongation of the rice stems, which may reduce grain yield through lodging. The water layer is therefore lowered. A lowering of the water depth causes higher infestation with weed seeds and faster weed growth. When the crop canopy closes, new weed growth is almost completely repressed. At this stage the watertable has to be lowered as much as possible, but with the highest parts of the field still just under water.

After seeding, the weeds are treated twice if necessary: the monocotyledons 10-14 days in the postseeding drainage period, the dicotyledons 25-35 days after seeding. The application of 2-4D needs a lowered watertable to establish sufficient contact with the weeds, but the stem feet of the rice plants have to remain under water. This treatment is often combined with the first nitrogen application. After zero, dry and dry/wet tillage, monocotyledons mostly need a chemical treatment; after wet tillage this is not always necessary. Dicotyledons are only incidentally treated.

Ten Have (1967) found the urea was most effective if the fields were surface drained for 4 days and the urea applied after the first two days. Only at the fourth nitrogen dressing (never carried out in practice, solely in the experiments) is surface drainage inadvisable, because of possible drought damage to the rice plant or panicle.

Heavy growth of algae is often related with a poor crop, finding expression in slow length growth and a yellowish-green colour of the leaves. Application of nitrogen fertilizer on an already present cover of algal has usually little effect; extended drainage before fertilization causes them to dry and to die if weather conditions are favourable. Already after reflooding without fertilizing, the recovery of the crop is apparent. Recovery is better with nitrogen fertilizer at the right growth stage.

Pre-harvest drainage. The field is drained about two weeks before harvest to promote even drying of the crop and to facilitate threshing afterwards. As the paddy is handled in bulk, high percentages of green grains decrease the quality during storage before artificial drying.

Drainage increases the soil-bearing capacity, facilitating traffic and thus increasing the threshing capacity of the combine.

The time needed to drain the soil, and the effect of drainage depend for the removal of the surface water on the:

- evenness of the surface and the trench system

for the removal of the soil water on the:

- depth, structure and moisture content of the tilled layer
- weather conditions promoting evapotranspiration in absence of precipitation
- plant transpiration activity (stage of yellowing)

Varieties with a short growing period are more sensitive to drainage, as the plants are still green and have relatively high transpiration rates at ripening.

1.5.4 Fertilization

Generally only nitrogen is applied (as urea). The profitability of phosphate and copper applications are indicated but will not be considered here (11.3).

Urea application. Basal nitrogen application before sowing is absent. Four top dressings after sowing are possible, but they are never practised. The application times depend on the growth stages. For the long growth duration varieties they are shown in Table 9; the amounts vary from 0-80 kg urea per hectare, in experiments with up to 120 kg. The most favourable moment and the amount depend on soil tillage and will be dealt with in chapter 10.

The second and third are standard; the first is always included after zero tillage, mostly after wet tillage, and for extremely yellow crops; the fourth is only experimental.

Nitrogen balance. Burning the stubble considerably reduces the quantities of organic matter returned into the soil (Table 10) and the nitrogen contents and C/N ratios of these (Table 11).

Table 9. Nitrogen fertilization and growth stages.

1st	nitrogen application	at early tillering	after 20-25 days
2nd	nitrogen application	at panicle initiation	when first internode is 2 cm long
3rd	nitrogen application	when panicle have differentiated	when panicle inside sheath is 2 cm
4th	nitrogen application	when 50% of the panicles flowers	when 25-50% of the panicles flowers

Table 10. Quantities of plant material incorporated in the soil by dry tillage (dry weights).

Untreated stubble	Stubble burned only	Stubble squashed and burned	Stubble cut and burned
4500 kg/ha	2850 kg/ha	2500 kg/ha	1750 kg/ha

Table 11. Nitrogen content and C/N value of plant material incorporated in the soil.

	Old stubble	Stubble regrowth and weeds	Mixed old and regrowth stubble	Combine straw	Ash	Fellow vegetation
% N	0.5	1.3	0.7	0.8	0.1	1.1
C/N	47	23	.	33	14	22

. not estimated

Tillage returns some 20 kg nitrogen into the soil per ha when the stubble is not treated, but only 0-2 kg per ha after cutting and burning of the stubble. After a fallow period, when burning is never practised, 10-40 kg nitrogen per ha are returned with the old untreated partly regrowth stubble and weed vegetation.

Nitrogen withdrawal by the rice crop is 80-100 kg N/ha. The rate of nitrogen through fertilizer is 40-100 kg N/ha.

Every season 40-50 kg N/ha is removed from the soil with the paddy transport. In combination with an intensive stubble treatment, a total of 60-70 kg N/ha is removed from the soil, in which losses due to denitrification are not incorporated.

To the soil is added every season by fertilizers 40-100 kg N/ha, and some unknown amount of fixed nitrogen by algae and bacteria.

The total of soil nitrogen (0.03% N) accounts for 5250 kg N/ha in the upper 15 cm. The seasonal amount of 40-70 kg N/ha withdrawal from the soil by paddy transport and stubble burning amounts to 1-2%, the nitrogen withdrawal per crop to 2% of the total stock. A review on removed and added amounts of nitrogen are given in Table 12.

Table 12. Nitrogen stock, removal, and dressing (kg N/ha) for soil and field in the Wageningen Polder.

Soil stock	From and to the soil		From and to the field	
	removed	returned	removed	added
	8-100 by crop	0- 20 by stubble and weeds	40-50 by paddy	40-100 by fertilization
		40-100 by fertilization	0-20 by stubble burning	.. by fixation
		.. by fixation	..by denitrification	

..=values unknown

2 Literature review

2.1 REMARKS ON DEFINITIONS

To avoid misconceptions, it seems desirable to explain the meaning of some expressions and terms used in the following chapters.

In the rice cropping system have to be distinguished the origin of the water and its management, the crop establishing method, and the type of soil tillage. The different systems and their components are:

production system	origin of water	crop establishment method	water management
lowland	irrigation	transplanting	flooded 1 week after transplanting or seeding, sometimes with drainage periods till 1-2 weeks before harvest
	irrigation	direct seeding	
	rain	transplanting	dependent on rainfall
upland	rain	direct seeding	dependent on rainfall

The study concerns only irrigated rice production.

The terms used to describe soil tillage in the cultivation of rice are rather confusing. Plowing may refer to soil preparation in flooded fields as a start for aggregate destruction in the puddling system, but it is also used to describe clod formation on dried fields (after which the clods are left to dry further). To distinguish between these two treatments, it seems advisable to use the terms wet plowing and dry plowing, respectively.

2.2 TILLING METHODS

Land preparation in lowland rice cultivation is usually associated with puddling, practised already centuries in Asia where circumstances favour its application. Nevertheless some 30 to 40% of the world's rice, including all upland rice, comes from soils prepared when dry (Moomaw, 1971), mainly in North and South America (where puddling is entirely omitted) and in Japan, where dry treatment is followed by several puddling treatments. In America, dry land preparation is associated with the always rather long periods of low rainfall and the possibility of irrigation with water from catchment areas outside rice-producing areas, Japan uses dry-land preparation because of the usually rather coarse texture of the rice soils, whereas in the tropics with dominantly fine-textured soils wet treatment is favoured. In the tropics most of the rice is planted on land flooded naturally during the rainy season. These lands are only suitable for rice production in combination with wet tillage, as they are either too dry or too wet for upland crops and dry tillage.

The *depth of soil tillage* is generally low: Moomaw(1971) mentions an average of 12-15 cm for Japan. The effect of soil depth on yield has been investigated by Briones (1969), who found a proportional increase between 0 and 40 cm (without nitrogen dressing), whereas, beyond this depth, the yield increase was less pronounced. On plots dressed with nitrogen, the yield markedly increased with soil depth down to 30 cm, only slightly with soil depth down to 30-40 cm, and not at all with deeper soil. Dressing with 50 kg N per ha led to an increase equalling that caused by an increase in depth of soil from 10 to 30 cm.

An example of *wet tillage operations* has been supplied by RICE (1967) as cited by Sanchez (1969),for the Philippines. Four tillage operations are recommended in a period of 30 days. The first is plowing at the end of one's week's flooding. One week after subsequent draining, harrowing follows as the second operation; it serves to destroy aggregates and allows the newly exposed clods to soak. The third and fourth operations are harrowings at intervals of a week. The ultimate result is a thick, plastic mud with a moisture content of some 60 to 90%. All operations take place in a shallow layer of 12-15 cm; deep tillage increases yields only in soils with a hardpan.

Davis (1964) gives an example of *dry tillage operations* in the United States, where it is advised to apply deep plowing when the soil is dry and to wait, afterwards, 10 days to enable the clods to dry and to promote weed kill. Then the seedbed is prepared on a dry soil to promote seedling establishment, resulting in a heavier crop. For Surinam, ten Have (1967) gives the same advice, but he prefers wet seedbed preparation.

The purposes of tillage in rice production are usually taken to be aeration of the soil, incorporation of organic matter, loosening of the soil to increase the permeability in the plowed layer, creation of a hard layer to reduce losses of water and nutrients, and making of conditions favourable for seed germination or transplanting (e.g Garrand, 1966; Madramootov, 1971). This list may suggest that tillage aims at benefiting the soil,whereas the main purpose is to benefit the economy of rice production. More serious is the objection that many experiments contradict the useful effect of tillage carried out as described above: aeration of the soil induces losses of nitrogen (IRRI, 1972), aeration and loosening of the soil are not directly advantageous to the rice plant. Indeed, Matsubuayashi (1967) has reported an increased mineralization caused by intensive drying of the soil, and in coarse soils bulk density increases through compaction, causing higher grain yields (Moomaw, 1971).

The supposed increase in permeability of the plow layer is absent; on the contrary, puddling of the soil after clod-making reduces it a hundred or even a thousand times (Sanchez, 1968). Churning the soil is in itself hardly profitable, and only in combination with a preceding nitrogen dressing may it be useful in bringing the fertilizer below the oxidized layer, thus increasing yields (Matsubuayashi, 1967). However, puddling fine-structured soils in the tropics does not result in hard layers (Sanchez, 1968); seedling establishment is reported to be superior on unpuddled beds (Davis, 1964).

The incorporation of organic matter usually increases the amount of ammonia released after flooding (Aspira, 1966), but in soils low in organic matter the incorporation of weeds and straw may have the opposite effect of immobilizing the nitrogen. Other authors, however, report little or no danger of nitrogen immobilization in reduced soils. The level of fermentation energy release is low at the different stages of organic matter breakdown by anaerobic bacteria, causing no soil nitrogen to be immobilized in bacterial body increase (Williams, 1968; Ponnamperuma, 1964).

To throw some light on the problem of *dry tillage versus wet tillage*, Sanchez (1968) has reviewd the data on performance of rice on puddled and aggregated soils. His experiments indicated equal growth patterns, yields, and nutrient uptake. The main effect of puddling he found was a drastic reduction in water movement with drainage rates reduced to a thousandth of rates in aggregated soils.

In his pot trials, comparing dry and wet tillage (after a basal nitrogen dressing) in their influence on rice growth and production, the soils were exposed to alternate drying and wetting. This may have influenced his results, and the effects were not analysed. From his field trials, he concluded that in in the aggregated treatment a permeable subsoil induces large nitrogen losses. But he did not mention exactly how he prepared the aggregated system so that discrimination between wet and dry tillage is not easy. Nevertheless he concludes that the amounts of nitrogen in different forms in the puddled and the aggregated systems are different, and that a nitrogen management system known to be efficient in puddled soils may not be so in aggregated soils.

Beneficial effects of dry tillage without subsequent puddling have been reported from Surinam (Hasselbach, 1966; ten Have, 1967), from Japan (Dei, 1973), and from the United States (Davis, 1964). Dry tillage has important advantages in management, and it increases the suitability of the soil for a multiple-cropping system (Sanchez, 1969).

Tillage, as part of the agricultural production process has two roles: it is a management operation and a regulation of the physical soil conditions, so that its benefits also have to be considered in the light of costs and returns (Kuipers, 1963), which greatly influences the choice of production system.

The combination puddling-transplanting has been favourable in the past, and often continues to be profitable. Its main advantages are a reduction in occupation time of the land by the rice crop, and the establishment of a lead over the weeds for the crop (Greene, 1966). However, the recent shortage of manpower favours sowing and hence the combination of transplanting and puddling looses ground. This means that puddling as a tillage treatment has to be reconsidered and to be compared with other soil treatments.

In considering tillage and puddling in terms of costs, alternatives for the beneficial effect of tillage on weed control have to be evaluated, especially where other beneficial effects of puddling (lowering soil permeability) or tillage (bringing fertilizers to greater depths) are absent. This especially applies to fertile heavy-textured soils rich in organic matter in tropical regions.

Tillage in general, and puddling too, also encourage seed emergence and seedling establishment. Again the decision is partly a matter of costs. Though the old puddling system maintains a high nitrogen and organic matter content of the soil (Green, 1953), its favourable influence is more due to continuous flooding than to puddling (IRRI, 1972). The puddling system is suitable for the large area of fine-textured soils which depend on rainfall for flooding.

The fine-textured soils consist, when dry, of large elements setting a limit to the use of traditional tools and power sources during dry plowing.

Khan (1971) reports that tillage and threshing form 50% of the total costs of rice production, based on contract operations. Indigenous mechanization is necessary to promote crop production, as the farmers in the developing countries pay considerably higher prices for machinery than in industrialized countries, whereas the returns are lower. Still the costs of machine-tillage in contract operation is reported to be half of those when buffalo are used (Lenn, 1969).

In considering zero tillage as a possible alternative in rice production, Moomaw (1971) reported zero and minimum tillage to be less successful on fertile, fine-textured and wet soils where it is difficult to destroy vigorous weed growth by chemical means, so that costs are higher than those of tillage. Yields after zero or minimum tillage are reported to be equal (Mittra, 1968; IRRI, 1972) or even higher (Saha, 1968) than after conventional methods. Mittra mentions that tillage reduces the time needed for land preparation from 30 to 10 days; IRRI (1972) and Seth (1969) consider it especially suitable for soft marsh soils, where normal cultivation is too difficult or involves excessive costs for land preparation.

2.3 TILLAGE AND THE SOIL

2.3.1 Morphological soil characteristics

The discussion on the morphological aspects of rice soils is limited to these relating to tillage.

Sanchez (1969) observed a laminar structure in the tilled layer of rice soils which he ascribed to slow sedimentation of the puddled mass in the flooded field. With the aid of thin sections, Saito (1971) showed this layer to consist of three sublayers. The uppermost, about 15 mm thick, was built up of fine particles separated during flooding and puddling. The second was sandy, consisting of single grains. The third was again compact but showed no differentiation of particles. Throughout the plow layer, there were pores formed by gas developed during the reduction process.

In heavy-textured soils in the tropics, plow pans or hard layers are absent in the lower part of the tilled layer (Sanchez, 1969).

Bouma (1969) reported the advantage of micromorphological methods for studying the influence of tillage on the Dutch soil.

2.3.2 Physical soil properties

In reviewing the influence of puddling in rice fields on physical soil properties, Sanchez (1968) defined it as the process of soil aggregate destruction by mechanical force in soils with a moisture content exceeding the moisture equivalent. He distinguished two phases in the process: (1) wetting the soils; (2) application of the mechanical force. Among the effects are a destruction of soil aggregates and macropores, an increase in microporosity, an increase in soil-moisture retention. Water movement is drastically reduced within the mass, and from it by evaporation, by percolation and probably by plant roots.

During flooding, the soil first takes up water until it is saturated. Afterwards the already saturated soil continues to increase its moisture content by clay lattice expansion for 6 weeks in the upper 30 cm (Strickland, 1969).

Puddling largely reduces soil permeability to a low level as apparent from data supplied by Abe (1973) for heavy, gray lowland clay soils in use for rice production in Japan, which ranged from 0.1 to 2.3 cm per day. He also observed a decrease in permeability with increasing clay content; at 50% clay the permeability is about 0.1 cm per day. He considered permeability to be too low; addition of sand improving soil structure, pipe drainage, subsoil and mole drainage may change the situation. He mentions that 18% of the rice soils in Japan have clay contents above 25% and need such improvement in permeability.

In rearranging Surinam data of Elders (1967), I noted a tendency for soil permeability to decrease with increasing number of years of puddling cultivation. Van Amson (1968) reported in Surinam highly productive rice soils to have permeability above 100 cm/day; and less productive soils permeabilities between 1 and 70 cm/day, despite the low pH of these soils (4-4.5).

Puddling destroys some of the aggregates. For those remaining, stability increases due to the reducing conditions after flooding. This stabilization can be ascribed to an increase in ferric iron and to gas development in the soil, both encouraging aggregation (Ahmad, 1963).

Continuous flooding and rice cropping cause a breakdown of waterstable aggregates resulting in deflocculation of the soil (Reed, 1939).

2.3.3 *Chemical soil properties*

The influence of flooding on the chemical properties and on the nutritional aspects have been thoroughly studied by Rodrigo (1961), and by Ponnamperuma (1964) and his coworkers (IRRI, Annual Reports 1964-1972).

Analysis of solutes in soil moisture, started by Gurgess (1922) and by Eaton (1959) for upland soils, have been used to study chemical aspects of flooding. Soil moisture is obtained by gravity flow (Rodrigo, 1961; Ponnamperuma, 1964). To allow this extraction, clod structured soils stabilized with benthonite are used. Whereas this method cannot be applied when differences in tillage treatment are encountered. Yamasari (1972) and IRRI (1967) used soil moisture analyses to study nutritional aspects for rice.

Flooding brings about drastic changes: oxygen disappears, the concentration of carbon dioxide increases, the redox potential decreases, pH and conductivity increase, nitrate nitrogen disappears, while ammonium nitrogen accumulates, various organic substances are formed, iron and manganese phosphates, and silica increase in solubility, and divalent and monovalent cations move from the absorption complex into the soil solution (Ponnamperuma, 1964).

Flooding and pretreatment of the soil influences the nitrogen relations in lowland rice soils. The flooding induces a mineralization of the organic matter, causing an increase in ammonium production, but a loss of nitrate soil nitrogen due to denitrification. Patrick(1964) noticed that an increase in ammonia production after flooding was followed by a decrease (after 5 weeks of flooding) to a low level.

Ponnamperuma (1964) found an asymptotic increase in available (water-soluble) ammonia after flooding. He found a linear increase in the maximum concentration of available ammonia after flooding with increasing organic matter content of the soils. In soils with a high exchange capacity, the ratio between the water soluble ammonia and the total amount is 1:10.

Strickland (1968) found that the available soil nitrogen remained at the same level for 8 weeks after flooding: thereafter it decreased, both on cropped and uncropped fields. Neither did nitrate contents differ for cropped and uncropped soils.

Koyama (1971) found the release of soil nitrogen to be dependent on the temperature during the growing season. During vegetative growth, only a third of the total soil nitrogen mineralizes in northern Japan, more than half of it in southern Japan. During ripening, these data are a third and a sixth, respectively. For Thailand, he found an even higher increase during the vegetative period (Table 13).

As already known in 1909 to Russel, drying and subsequent rewetting of the soil results in an increased decomposition of organic material. For Japan, Shiori (1954) calculated the increase at 20 kg nitrogen per hectare. This quantity is higher for lowland rice soils than for upland soils; in badly drained paddy fields, it is higher than under normal circumstances. According to Harada (1968), one drying/rewetting operation in Japan causes the breakdown of about 10% of the organic matter.

For the United States, Patrick(1964) reports a total loss of 20% in subsequent cycles of drying and submergence, by decrease in organic matter available to the micro-organisms. The main part of this loss occurred in the first cycle of wetting and drying. At a steady optimum moisture content (between field capacity and wilting point), no soil nitrogen losses seem to occur. In a continuously flooded soil, he supposes that all nitrogen losses are due to nitrification of the nitrogen already present before flooding.

Briones (1966) has reported for the Philippines that puddling increases the soil ammonia level after flooding, but that in most of his experiments this increase is only temporary and disappeared after two weeks. The same seems to apply to Japanese soils (Sanchez, 1968). Several theories have been drawn up to explain this phenomenon, but no proofs have been given (Sanchez, 1968).

Dei (1973), has summarized the results of his investigations in Japan on the effects of plowing and puddling. He concludes that a decrease in size of aggregates from 5 to 0.5 mm diameter results in an increase in mineralized nitrogen. Agitation of submerged aggregates increases mineralization of nitrogen, agitation of a mud does not. After flooding, small aggregates of

Table 13. Available nitrogen in kg per ha in the soil during four growth stages at different latitudes (after Koyama, 1971).

Growing phase	Northern Japan, 45 °N	Southwestern Japan, 35 °N	Thailand 15 °N	Values considered optimum in Japan
active vegetative phase	6	15	17	6
vegetative lag phase	11	15	12	13
reproductive phase	26	17	4	26
ripening phase	22	9	4	9

0.5 mm mineralize more nitrogen than a mud, by release of soil nitrogen after collapse of aggregates later in the growing season.

2.4 THE RICE PLANT

Rice is known to be moderately salt-tolerant, though differences between varieties occur.

The *salinity* of a soil can easily and accurately be estimated by measuring the electrical conductivity of a soil solution from the rooting zone. In this solution, salt concentrations are usually higher than in the irrigation water, on which most publications only report. Pot trials show stronger effects of the salinity than field trials (Pan, 1964), perhaps by greater variations in temperature , which cause changes in the transpiration rates of the plants. The effects of salinity on grain and paddy yield are more pronounced than those on vegetative growth (Pearson, 1961; Pan, 1964). Kaddah (1962) mentions that rice seeds are able to germinate at high salinity (conductivity up to 40 mmho/cm at 25 ^{o}C). This result has no practical significance as the seedlings are rather sensitive to salinity (Pearson, 1965). Kaddah (1962) mentions that 3.5-4 mmho/cm at 25 ^{o}C already seriously affects their growth. According to Pearson (1959) and Ehrencroon (1963), rice grown in pots filled with clay decrease in yield at conductivities of 4 mmho/cm at 25 ^{o}C. Choi (1964) found varietal differences in salt tolerance in culture solutions only in the range 0.1 and 0.5 g salt/100 g dry soil.

In general, the uptake of water by plant roots causes only small gradients in water content and suction near the plant root, unless the wilting point is approached. The water reservoir supplying the plant root is only small, however, as it is limited to a few millimeters around the root (Gardner, 1960).

Grain production depends mainly on number of panicles, number of spikelets per panicle, percentage ripening grains, and grain weight (Matsushima 1970).

According to Koyama (1972), some 60% of the tillers produce a ripening panicle in Thailand. Broadcast seeding may result in too many tillers per surface area and too dense plant populations (IRRI, 1972). Then mutual shading causes an imbalance between the photosynthetic production of carbohydrates and their respiratory consumption: only the leaves exposed to light are active in photosynthesis, those in the shade only consume assimilates. Under normal field conditions, the competition for light starts earlier than that for nitrogen (Tanaka, 1964).

According to Matsushima (1969), the number of spikelets per panicle is determined mainly in the period up to 43 days before heading, the percentage of ripening grains in the period from 43 to 19 days before heading, and the grain weight in the ripening stage.

Rice plants transport oxygen from their aerial parts to their roots (van Raalte, 1941) as quickly as in an air-filled space (Barber, 1961); transport decreases with the elongation of the stems, probably by lengthening of the pathway. During stem elongation the plants also form a root mat consisting of fine abundantly branched roots at the surface of the soil and new roots usually develop at the internodes in the floodwater (Alberda, 1953). Both are supposed to supply the deeper roots with oxygen. According to Bouldin (1966), the immediate surroundings of the root tips have no oxidizing influence, although ion uptake is concentrated there. This does not apply to the parts of the rhizosphere next to the older root parts. He attaches importance to the fact that carbon dioxide diffuses from the roots, meets calcium ions and forms carbonate precipitates.

Root activity can be measured in various ways (for a literature review see Yoshida, 1966). These measurements are based on the respiratory rate of the roots, but little evidence exists for a strong correlation between dye formation, and water and salt absorbing ability.

Literature on the influence of soil structure on rice root development is scarce. Sanches (1969) did not observe any differences; Dei (1973) found root development to be more favourable in aggregated soils than in muddy soils.

A special feature of rice roots has been mentioned by Ota (1970): the formation of 'lion tails' with severe soil reduction, toxic levels of hydrogen sulphide, organic acids of divalent iron, and with excessive nitrogen supply.

2.5 NITROGEN FERTILIZATION

2.5.1 Method of application

Rice yield is a function of inherent varietal characteristics and the environment. Hence, the amount of nitrogen applied, their proper timing, and effect on grain yield depend on many circumstances (Evat, 1964). The most important are: season, variety, spacing, method of application, and available ammonia in the soil.

In the rainy season, solar radiation is low, and the effect of dressing will be proportional to it. Dew and rain can cause heavy losses of nitrogen from the plant, amounting up to 30% of total nitrogen accumulation in the aerial parts (Tanaka, 1964), mainly from the lower shaded leaves and especially with heavily fertilized indica varieties.

The applied nitrogen is partly taken up by the rice plants in a wet season 10-35% is recovered by the plant roots, as against 20-60% in a dry season (Racho, 1968). According to Jayaraman (1969), a split nitrogen application (half at planting, half at tillering) is most effective during late maturation, whereas during early maturation the nitrogen can be applied as a single dressing.

Competition for nitrogen starts later than that for light (Tanaka, 1964). Hence varieties with short narrow leaves, rich in nitrogen, already react to nitrogen application when there is little mutual shading (Tanaka, 1965). Roots of varieties weakly responding to fertilizer develop more actively. When nitrogen is added in excess, roots of such varieties will absorb large amounts of nitrogen relative to other varieties and will develop weak roots rich in carbohydrate. In addition,tillering will increase, increasing mutual shading, and disturbing the balance between photosynthesis and respiration. Hence less assimilates are transported to the roots (Tanaka, 1964). To estimate tillering, Tanaka (1965) found the nitrogen content of aerial parts to be a good parameter.

Nitrogen may be placed shallowly, at depths between 5 and 15 cm, or broadcast on the surface. Many data point to a higher uptake and larger grain yields with shallow placement (Patrick, 1967; IAEA, 1970). With non-lodging varieties and much sunlight, shallow or deep placement are better (Simsiman, 1967; Magnaye, 1968). Simsiman found a recovery of 68% with deep placement and 38% after slightly worked-in broadcast fertilization. Abichandai (1955) reports that slight incorporation of the nitrogen is superior to broadcasting on to the water.

The type of soil also plays a role. IAEA (1970) mentions that shallow placement in acid to neutral soils results in a 30-40% higher utilization of nitrogen than surface placement, but that no differences occur in soils containing calcium carbonate ($pH > 7$).

In Japan, Koyama (1971) reports that an average of 77% of the nitrogen in the plant at harvest originates from the reserve in the unfertilized soil. Fertilizer nitrogen contributes 8-55% to the nitrogen in those plants, depending on the placement depth of the basal supply and the local circumstances (IAEA, 1970). Up to 40% of topdressed nitrogen were recovered in the harvested crop.

Soil incubation experiments under both submerged and upland conditions (Assami, 1971) showed a 100% recovery of the applied ammonium fertilizer as inorganic or immobile nitrogen in soil after 6 weeks. The amount of mineralized nitrogen in soil was larger in the submerged soil than in the upland soil. The amount of the immobile added nitrogen was larger in the upland than in the submerged soil. The remineralization of the immobilized nitrogen stopped after two weeks, representing a quarter of the total immobilized part of the added nitrogen. The mineralization of the organic matter in soil proceeded rapidly for two weeks and continued slowly thereafter.

Koyoma (1972) reports 40-70% recovery of topdressed nitrogen within ten days for rice plants in Thailand. His data have shown that 60% of the nitrogen content at harvest originates from the soil reserve, and 40% from fertilizer (27% from the basal application, 13% from topdressing).

Differences in nitrogen absorption during first and second crops have been reported (Koyoma, 1972) but perhaps fluctuations in weather may have influenced the drying of the soil.

Dei (1973) points to the smaller losses in aggregated than in muddy soils and the residual effect of the applied nitrogen tends to be higher. The nitrogen added to a granulated soil disperses throughout the 15 cm tilled layer, whereas in a muddy soil most of it stays in the upper few centimeters.

On puddled soil, Breazeal (1939) found a greater loss of nitrogen applied as nitrate and ammonia than on granulated soils.

2.5.2 Water management and nitrogen fertilization

Opinions considerably differ on the most suitable water management for rice cultivation. According to Matsushima (1962), intermittant irrigation, midseason drainage and water percolating through the soil during submergence are widely practised in Japan. This practice must take account of the drought susceptibility of the rice plant, especially in the period 20 days before to 10 days after heading. In Malaya, contrary to his findings in Japan, he found no yield increase by inserting drying periods during crop growth, nor by encouraging percolation. In the Philippines, a long-term experiment (IRRI, Annual Report, 1969) also showed no beneficial effect of midseason drainage.

A dry fallow between two rice crops resulted in slightly lower following yields than flooding during that period. A 32-month trial with a combination of dry fallow and midseason drainage caused a nitrogen loss of 800 kg/ha. Percolation increased yields at conductivities of soil moisture above

1.6 mmho/cm at 25 °C but increased losses of nitrogen to 40 kg per hectare per season (IRRI Annual Report, 1969)

The internal drainage of the soils is reported from Japan to be related to the response of nitrogen application. Ill-drained soils showed a lower response than well drained soils to high rates of nitrogen (Seko, 1966). Miyasaka (1964) reports a higher yield response with split nitrogen dressings and mid-summer drainage on ill-drained paddy fields.

Flooding an air-dried soil stimulates denitrification and causes high nitrogen losses (IRRI, 1965). Continuous submergence, also between the rice-growing seasons, results in an accumulation of nitrogen (IRRI, 1969): indeed Tanaka (1963) found in such cases much larger amounts of ammonia than with late and intermittant irrigation. Hall (1959) also reported the absence of a yield-promoting effect of mid-summer drainage without nitrogen dressing, whereas a delayed initial flooding increased yield.

Strickland (1968) points to the inefficiency of nitrogen fertilization: 50% of the nitrogen applied may be lost by surface drainage after seeding.

Ten Have (1967) recommends flooding 2 to 4 days after fertilizing with urea (also Strickland, 1968; Tanaka, 1960). Tanaka (1960) mentions that in southern Japan 20% of the applied urea has been converted into nitrate within 48 hours and that adsorption on the soil particles is higher with urea than with ammonium sulphate, when its concentrations are high, e.g. around the granules.

Topdressing is usually practised on flooded fields, though some authors report a higher efficiency when fields are temporarily drained (Wyche, 1949; ten Have, 1967; Hall, 1959).

Ten Have (1967) mentions large increases in grain yield after split application to a surface-drained soil. Hall (1959) reports that grain yields increase with delayed dressings on a drained surface (43, 68 and 92 days after seeding), but Magnaye (1968) found no advantage in drained the field for topdressing.

2.5.3 Distribution of nitrogen fertilizer

The most favourable moment for topdressing is determined by the physiology, and in particularly by growth phase of the rice plant (Patnaik, 1967; ten Have, 1967; Murayama, 1967; Sims, 1968; Hall, 1968; Singh, 1962; IAEA, 1970). All these authors refer to dressings in which part of the nitrogen is given by shallow placement, and part as a topdressing either mid-season, at panicle initiation, at the booting stage, twenty days before heading, two weeks before primordial initiation, or at elongation of the internodes (varying between 48 and 68 days after seeding, according to variety).

All authors mentioned above report an increase in grain yields with split dressings, except IAEA (1970) which states that half the places yielded equal, half higher after a single dressing as with shallow placement before planting.

The results reported with topdressings classified as 'within 20 days before heading' fit in with the theory developed by Matsushima (1969): the V shaped rice cultivation method. According to this theory he divides the growth period into three stages: an early stage in which ample nitrogen supply promotes vegetative plant growth, a middle stage in which the nitrogen supply must be restricted to promote flower initiation and to restrict vegetative growth, and a late stage during which supply of nitrogen must be ample to allow grain to fill. To obtain a low nitrogen supply in the middle stage, he recommends draining the field to get rid of part of the soil nitrogen. The field is not dressed in the middle stage of growth, running from 43 to 25 days before heading.

The withholding of nitrogen supply through fertilization in the early part of the growing season can be achieved only in soils where nitrogen is the main yield-determining factor. The same results are achieved in cereals on fertile recently reclaimed polder soils in the Netherlands (de Jong, 1968).

None of the experiments described in this section paid much attention to the capacity of the soil itself to supply ammonia though this together with the nitrogen nutrition of the rice plant should be the basis of all nitrogen dressing. Nitrogen nutrition is important, especially in the two critical growing phases: maximum tillering and panicle initiation (Matsushima, 1966). Sufficient nitrogen must then be available. In the tropics soils with a large supply of ammonia need no nitrogen dressing; rice in soils with a moderate supply receive sufficient nitrogen at maximum tillering, but need a dressing at panicle differentiation. In soils with a low ammonia release, a large basal dressing or a split dressing are indispensable.

2.6 PHOSPHATE AND COPPER FERTILIZATION

Availability of phosphate is increased by reducing condition with flooding, by conversion of the less soluble ferric phosphate to ferrous phosphate (Ponnamperuma, 1965) and a preferable binding of aluminium and iron sesquioxides to organic acids (Bradley, 1953). Soil phosphate consists of organic and inorganic phosphate; the latter is mainly combined with Al, Fe and Ca. Chang (1964) showed Fe-P and Al-P to be the most important source for rice. He found the Olsen (1954) extraction method to be closest correlated with grain yields from pots, irrespective of the distribution of the inorganic P fraction in the soils.

The mineralization of organic phosphate is stated by Patrick (1967) to be of minor importance for P-nutrition of the rice plant. Basak (1962), however, shows mineralization of organic-P to be substantial.

Reports on correlation of grain yields with phosphate extraction method are reported for the Olsen extraction by Rodrigo (1960) in Ceylon, and IRRI (1967) in the Philippines and for the Bray-2 extraction method by Vajragupta (1963) in Thailand and Peterson (1963) in the United States.

P (Olsen) soil tests showed at each sampling date high correlations with grain yield and P uptake as assessed by the P content of the grain. Correlation was no better if medium to fine textured soils were tested by the Olsen method after submergence (IRRI, 1967).

In Surinam, ten Have (1967) reports a withdrawal of phosphate by the grain of 19 kg P_2O_5/ha. Phosphorus extractbale from soil with 25% HCl is 50 mg P_2O_5/100 g dry soil.

Copper dressing is reported by Coops (1964). He suggests rates of 3.5 kg/ha to kill snail and 10-750 kg/ha as a trace nutrient for rice.

2.7 VARIETAL ASPECTS

Differences between rice varieties are well known in literature. In the 1960s, IRRI started a comprehensive program for breeding high-yielding rice varieties. They have examined morphological characteristics associated with optimum utilization of available sunlight, plant nutrition and response to nitrogen fertilizer (IRRI, Annual Report, 1964 - 1972). Differences in root appearance and oxidizing effect of rice seedlings among some varieties are reported by Goto (1957). There are no literature reports about differences in yield reactions of varieties to soil treatments.

3 Methods

The classification of the Wageningen Polder, in parts and its position in reference to the Prins Bernhard Polder both in the Nickerie district is given by ten Have (1967) in his Figures 2 and 6.

3.1 ANALYTICAL PROCEDURES

Thin sections of soil. The samples were taken in the 1969 autumn season 3 weeks after sowing and two days after harvest.

The former were collected from sown fields which had been flooded for ten days after 2 weeks of surface drainage. They consisted of water-saturated soil. The latter samples were from fields surface-drained 3 times during the growing season for four days in order to apply urea, and were surface-drained 14 days before harvest. The samples consisted of moist soil with a moisture content of 50% of the dry weight.

The samples were collected in steel boxes (10 cm x 15 cm x 15 cm) in the field, thereafter they were dried; water-saturated samples formed some "unnatural cracks". They were sent to the laboratory in Wageningen (Holland), where thin sections were prepared as described by Jongerius & Heintzberger (1963), examined then under a Leitz Ortholax microscope with transmitting normal and polarized light (magnification 1-30 times). The terminology used in the description is according to Brewer (1964).

Moisture content. Samples for assessing moisture content of a field were collected from 5 to 15 sites, according to purpose and expected variation, with half-open tube augers 2 cm in diameter (up to 25 cm deep) or 4 cm in diameter (25-100 cm deep). The moisture contents were determined by drying at 105 °C for 24-48 hours to constant weight. They were expressed, on weight basis (g water per 100 g dry soil).

Bulk density. To determine bulk densities, undisturbed cores 10 cm in diameter, 5 cm high, were collected and dried as for estimation of moisture content.

Dehydration curves. Core samples identical with those used for bulk density determinations were tested at the Agricultural Experiment Station at Paramaribo. Equilibrium was established at pF 0.4, 1.0, 1.5 and 2.0 on a fine sand bed, at pF 2.3 and 2.7 on a kaoline bed and at pF 3.5 and 4.2 in a membrane press.

Extraction of soil moisture and its analysis. Undisturbed soil samples were collected in cylinders 10 cm wide and 10 or 25 cm long pressed into the flooded soil and afterwards tightly closed. The water was extracted within 8 hours from subsamples 5 cm long placed in cylinders 10 cm wide (Fig. 4) with a filter paper on the bottom. After the top of the sample had been slightly kneaded to establish a good contact, a vacuum of 70 cm Hg was applied for 30 minutes. The extracted water was collected in a bottle containing some paraffin oil and three drops of toluene to prevent evaporation and oxidation. Afterwards the water had still to be treated with nitric acid to dissolve some precipitate.

Two samples were combined (or four for the 10-15 and 15-20 cm layers) to obtain 20 cm^3 for further analysis. They were analysed at the Agricultural Experimental Station at Paramaribo by the usual methods (e.g. Kamerling, 1964) for sulphide, chloride, sodium, potassium, calcium, magnesium and iron.

Water permeability. Luthin's method (1957) was used, since Bipat (1966) had proved that it was also suitable for flooded soils. A plastic tube 10 cm

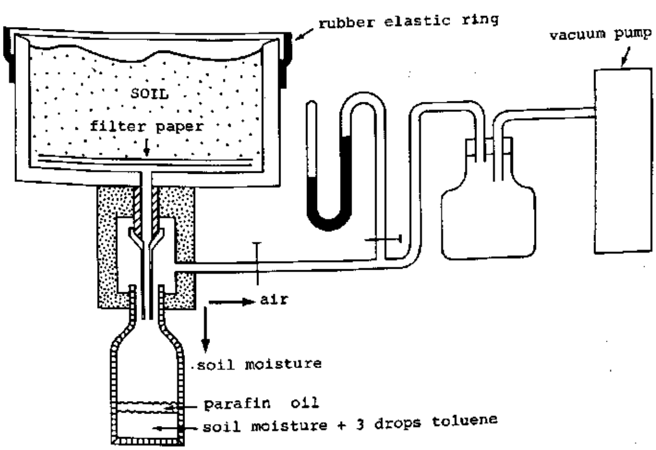

Figure 4. Soil-moisture extraction apparatus

in diameter was driven into the soil as decribed below (piezometer tubes). After installation, I waited 3 weeks before taking measurements to allow equilibration between the soil and the water level inside the tube in lowland rice soils. In swamp soils, no equilibration was needed and the level of flood water was used as datum line.

Matric moisture potentials. Three instruments (Fig. 5) were used: piezometers (water-passage surface 300 cm^2), tensiometers (w.p.s 35 cm^2) and hydraulic potential probes (w.p.s 0.03 cm^2). In the first and the last there is a direct contact between the soil moisture and the water in the equipment; in a tensiometer, the two are separated by the porous wall of the pot. For particulars, see below.

Piezometer tubes. To measure piezometer levels, tubes 10 cm in diameter and 50-150 cm long were pushed into the flooded soil. The soil inside was removed with an Edelman auger. For greater depths, the insertion of the tube was done in stages because of the stickiness of the clay. Depending on the soil horizon, the hole was extended 10 to 25 cm below the tube. A plastic bag on top prevented evaporation and entry of rain. The water in the tube was removed with a bailer to allow new water to enter, thus clearing any plugged pores along the wall of the auger hole.

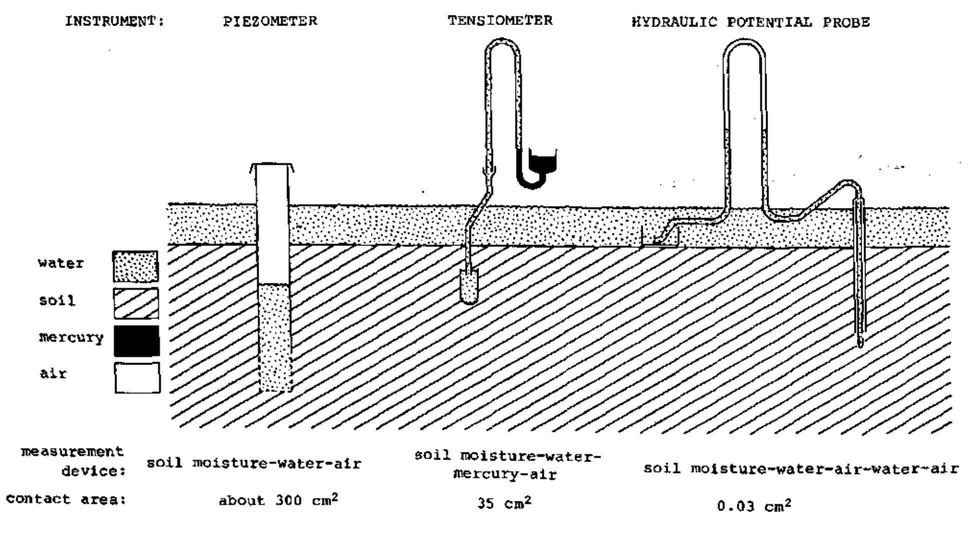

Figure 5. Equipment for measuring matric suction.

Differences in the length of the auger hole below the end of the tube had no effect on the rate of the reactions of the water level in the tube to external changes, unless the hole had reached a horizon with a different permeability.

Tensiometers. The tensiometers had porous pots 2 cm wide and 5 cm long. A plastic tube connected the pots with a mercury manometer, a water-filled tube was inserted between the mercury and the pot filled with water. Initially all water was free from air.

The meters were installed 2 weeks after sowing in a small hole drilled with a suitable auger. Only slight pressure was needed over the last 5 cm to bring the pots into position and to establish good contact between soil and pot.

The opening above the pot was closed with kneaded clay to prevent any direct contact between surface water and water in the pot.

Potential probes. Hydraulic potential probes as described by Fokkens (1968) were used. A stainless steel veterinary injector 1 m long with a loose inner tube (internal diameter 2 mm) was pushed into the soil to the required depth, and the inner tube was pushed 2 cm further, bringing an opening in the side wall of the inner tube (area 0.03 cm^2) into contact with the soil (see Fig. 5).

Electrical conductivity. Electrical conductivity was measured in the extracted soil moisture, to which no toluene nor nitric acid was added during the procedure, with a portable transistorized conductimeter (Cenco-34501).

Structural stability. The stability of soil was assessed by the wet-sieving method and end-over-end shaking.

In the wet-sieving method, samples with a core diameter of 10 cm and 4 cm high were taken from flooded soils at the end of the growing season. They were cut transversely into two parts. Each part was placed on the upper sieve of a series of seven sieves with 8, 4.8, 3.3, 2.0, 1.0, 0.6 and 0.3 mm mesh, shaken for 30 minutes at 55 strokes per minute over a stroke of 18 cm. Later the fractions were combined into three groups: 0.3 mm, 0.3-8.0 mm, and 8.0 mm and calculated as percentages of total dry weight. The 0.3-8.0 mm fraction is called percentage relatively stable aggregates. Figures are median values of 3-6 samples.

In the end-over-end procedure, the fraction obtained on the 1 mm sieve, after the wet-sieving procedure, was put in a 50 cm^3 cylinder filled with a NaCl solution 750 mg/litre. After 1000 rotations at 16 rotations per minute, the dry weight of the remaining aggregates was estimated and expressed as percentage of the 1.0-2.0 mm fraction, which was seen as a measure of aggregate stability. Figures are median values of 3-6 samples.

Incubation.

Ammonium production of the soil. To estimate ammonium production in the soil, in a 40 m^2 dressed plot, five plastic tubes, 20 cm long and 10 cm wide, were driven into the soil between rice plants. At the end of a period the soil in the tubes between 0 and 7.5 cm and that between 7.5 and 15 cm was collected in plastic bags 1 mm thick.

Three samples were taken at each depth from each tube. In addition, fifteen samples outside the incubation tubes were collected at each depth. The series of samples were bulked and mixed at their field moisture content by kneading in the plastic bag after removing air. From the bulked sample, 25 g was taken for moisture estimation. To another 25 g, 200 cm^3 KCl solution 1 mol/litre was added, and shaken for an hour, whereafter the bottle with the sample was kept overnight at 4 ^oC, and then filtered. Of the filtrate, 20 cm was distilled in a steam distiller after addition of aqueous NaOH 30 g/100 ml. The destillate was caught in a boric acid solution 1.5 g/100 ml and analysed for ammonium. Values were expressed per kg dry soil, or per ha.

Phosphate in soil. With a small peat auger, samples of about 500 g were taken. Phosphate was estimated in samples at field moisture by Olsen's method (1954) after thorough kneading of the soil in a plastic bag. If the samples originated from surface-drained or dried soils, they were moistened with distilled water immediately before kneading. Of the sample, 25 g was used to estimate moisture. To another 25 g, 200 cm^3 of $NaHCO_3$ (pH 8.5) solution 0.5 mol/litre and three teaspoons of phosphate-free activated carbon black were added. After shaking for half an hour in a 250 cm^3 bottle, and settling for one hour, the suspension was filtered. To 120 cm^3 of the colourless filtrate, 20 cm^3 of ammonium molybdate solution 15 g/100 ml and 80 cm^3 distilled water were added. This solution was measured against a standard series with a Lange colorimeter and a Kipp galvanometer.

3.2 POT EXPERIMENTS

As a rule, the pot experiments were in the open. Fresh soil was gathered from the upper 10 cm of the experimental field on the "4th reeks" in the Wageningen Polder. The soil was collected in the 14-day period of surface drainage before harvest, in solid cubic blocks, of which one was placed in each bucket of 7.5-10 litre. Afterwards the soil contents of the buckets were adjusted to the same weight, each bucket containing 3 kg dry soil with a moisture content of about 70% (w/w).

Most experiments included three soil moisture contents (70%, 40% and 10% before submergence). The 70% level corresponds with the moisture content in the field. The 40% level was obtained by drying the soil in the bucket in the open; the 10% level was obtained by subsequent drying of handmade clods from the 40% level. In Experiment 1 a fourth level was included of 3% moisture, to which clods from the 40% level were placed for 24 hours at 70 °C with forced ventilation. During drying, all buckets were covered overnight and during showers to prevent rewetting.

After obtaining the desired moisture level, the soil was made into clods or mud. The clod structure was made by fragmentation by hand. The soil was flooded immediately afterwards to prevent drying. A mud structure was formed by completely puddling the soil by hand after flooding and wetting the soil. During puddling, the surface water was temporarily removed.

Presoaked seeds were sown in containers with 1-2 cm soil; the seedlings were transplanted 7-10 days later, depending on the experiment, with 9 plants per bucket, continuously flooded (when necessary, tap water was added). After a week, losses were replaced with plants from the nursery. Fertilizers were applied at basal rates and were incorporated in the soil or, for topdressing, on the soil surface without surface-drainage. Nitrogen was applied as urea (48% N), phosphate as superphosphate and copper as $CuSO_4 . 5H_2O$.

The results mostly refer to shoots, not to grains, as setting was rather irregular, and protection of the filling grains against insects and birds was inadequate in most seasons. To estimate yields, shoots were dried at 70 °C. Shoots were analysed for total N, P_2O_5, K_2O and CaO at the Laboratory for Soil and Crop Testing at Oosterbeek, Netherlands.

In some experiments exchangeable ammonium was estimated in samples from the buckets taken just before basal dressings or transplanting and just after harvesting shoots.

The following seven experiments were carried out.

Experiment 1. Effect of previous soil drying intensity on tillering with clods.

Spring sowing 1969. Variety: Apura (145 days). Moisture content previous to flooding 70, 40, 10, 3%. Soil structure: clods. Replicates 4.

Experiment 2. Effect of previous soil drying, soil structure and split nitrogen top dressing on shoot yield.

Spring sowing 1970. Variety Acorni (115 days). Moisture content previous to flooding 70, 40, 10%. Soil structure: mud and clods. Nitrogen fertilization 35 and 56 days after seeding, at levels with applied amounts of 0-0 and 432-432 mg N per pot at respective dates. Shoot harvest at three growth phases: panicle initiation, panicle differentiation and flowering, at 34, 55 and 72 days after sowing, respectively. Replicates 3.

Experiment 3. Effect of previous soil drying, soil structure and basal nitrogen dressing on shoot yield.

Autumn sowing 1970. Variety: Awini (125 days). Like Experiment 2, except for nitrogen fertilization: basal dressing at three levels of 0,192 and 384 mg N per pot, topdressing at 45 and 74 days after sowing of 432 mg N per pot per date for all pots. Shoot harvest at three growth stages: active tillering, panicle differentiation and at flowering at 44,73 and 87 days after sowing, respectively. Replicates 3.

Experiment 4. Effect of soil structure and climate on shoot yield.

Unlike the other experiments, in Wageningen, Netherlands in 1966. Variety: Galibi (140 days). Moist soil was sent from Surinam, deep-frozen to 17 ^{o}C, thawed out and afterwards heated and force-ventilated at 70 ^{o}C for 48 h. Soil structures: aggregates, paste and mud. Climates achieved in a phytotron: 85% air humidity and 95% air humidity. Shoot harvest at 60 days after seeding. Replicates 2.

Experiment 5. Effect of previous soil drying and puddling intensity on tillering with mud.

Spring sowing 1969. Variety Apura (145 days). Moisture content previous to submergence 70, 40 and 10%. Soil structure soft mud and paste. Replicates 4.

The soil treatment differed from the puddling in other experiments. The paste was made by puddling the soil by hand after pouring off surface water and water from below the surface. The soft mud was made by puddling the soil by hand in the presence of surface water. Replicates 4.

Experiment 6. Effect of wetting and subsequent drying of soils on exchangeable ammonium in the soil and shoot yield.

Spring sowing 1970. Variety Acorni (115 days). Two sub-experiments

(1) Clod structure. Redrying clods with a moisture content of the clods before wetting 10%, after wetting 70%, after subsequent drying again 10%, and unrewetted clods.

(2) Mud structure. Redrying soil mass with a moisture content of the soil

mass before wetting dried down to 40%, wetted to 60% and subsequently dried to 40%, and unrewetted soil.

No nitrogen fertilization. Shoot yield 34 days after seeding at active tillering phase. Replicates 3.

Experiment 7. Effect of soil structure, nitrogen, phosphate and copper fertilization at four soils on grain yield.

Spring sowing 1971. Variety Acorni (115 days). Two soil structures: clods, with a moisture content before drying of 10% and mud with a moisture content previous to drying of 50%. Four soils were collected: A ("8th reeks"), B (experimental field,"4th reeks"), C (experimental field, "1st reeks") and D (Prins Bernhard Polder). The procedure for soil collection differed from that of other experiments. Soils were collected one or two weeks after harvest and the soils differed from one another in moisture content.

Nitrogen fertilizer 432 mg per pot per dressing was applied at 20, 40 and 58 days after seeding. Phosphate was applied 20 days after sowing at 2 levels (0, 270 kg P per ha). Copper was applied 20 days after seeding at two levels (0 and 27 kg Cu per ha). Replicates 3.

3.3 FIELD TRIALS

Soil tillage treatments are defined in 4.1.1. The field trials were on the area from which the soil was taken for the pot experiments described in 3.2. The fertilization plots were 5 m x 10 m or 4 m x 10 m, separated by strips 1 m wide on which the plants were cut just before flowering to avoid side-effects and seed dropping.

Sowing was by plane at 90 kg/ha, except in trials on sowing rate and variety, where it was by hand.

All plots within a trial were harvested by hand on one day or within two days. The panicles were mechanically threshed. The paddy was weighed when still moist, sampled for moisture analysis (by drying and weighing, or electrically), and grain yields were calculated on the basis of 14% moisture.

Shoots were sampled; plants, tillers and panicles were counted in duplicate per fertilizer plot with iron frames of ¼ m^2 at least 1 m from the sides of the plot.

Nitrogen (urea 48% N) was applied by hand and, for the variety Apura, in split dressings at the growth phases (1) active tillering, (2) panicle initiation (first internode of 2 cm), (2) panicle differentiation (panicle 2 cm long inside the leaf sheath), and (4) at 25% flowering, being about

25, 65, 85 and 100 days after sowing, respectively. For the varieties Awini and Acorni, nitrogen was applied at (1) tillering, (2) panicle differentiation, and (3) at 25% flowering, corresponding for variety Awini with about 25, 65 and 85 days and for variety Acorni with about 25, 45 and 65 days after sowing.

Field Trial 1. Effect of seed rate, nitrogen fertilization with four tillage treatments on grain yield.

Spring sowing 1969. Variety Apura (145 days). Four idential trials with the tillage treatments wet, dry/wet, dry and zero, for which the field was divided into four separately managed plots. Sown by hand with 30, 60, 90 and 120 kg/ha and fertilized at 4 nitrogen levels with 30, 60, 90 and 120 kg N/ha, divided equally over the three split dressings, in 4 replicates per plot (shoot data from 3 replicates).

Field Trial 2. Effect of total and split nitrogen dressing on grain yield and four tillage treatments.

Autumn sowing 1969. Variety Apura (145 days). Four identical fertilizer trials with tillage treatments wet, dry, dry/wet, dry and zero, for which the field was subdidived into 4 separately managed plots. The plot with zero tillage was left out of the trial through failure of seedling establishment. The distribution of total and split amounts are shown in Table 14, and quadruplicated for each tillage plot.

Table 14. Split application of urea for the 12 treatments in Field Trial 2, in kg/ha.

Dressing	Treatments													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
first	0	0	0	0	0	0	30	0	0	0	30	60	30	90
second	0	0	0	30	0	30	30	30	60	90	60	60	90	90
third	0	30	60	30	90	60	30	90	60	90	60	60	90	90
total	0	30	60	60	90	90	90	120	120	180	150	180	210	270

Table 15. Split application of urea for the 21 treatments in Field Trial 3.

Dressing	Treatment																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
first	0	60	30	30	30	40	40	0	0	40	0	0	0	0	40	0	0	0	0	0	40
second	0	30	60	30	30	90	50	30	60	40	40	40	50	90	80	40	80	60	120	90	50
third	0	30	30	60	30	50	90	60	30	40	40	40	90	50	0	80	40	120	60	90	50
fourth	0	0	0	0	0	0	0	30	30	0	40	40	40	40	0	0	0	0	0	0	40
total	0	120	120	120	90	180	180	120	120	120	120	120	180	180	120	120	120	180	180	180	180

Field Trial 3. Effect of various combinations of nitrogen application and four tillage treatments on grain yield.

Autumn sowing 1970. Variety Apura (145 days). The four plots in the Field Trials 1 and 2 were subdivided into four subplots with the tillage treatments wet, dry/wet, dry and zero tillage. The combinations of nitrogen distribution shown in Table 15 were triplicated for each subplot.

Field Trial 4. Effect of variations in soil treatment within the tillage treatments wet, dry/wet and dry, and of two nitrogen levels on grain yield.

Autumn sowing 1970. Variety Apura (145 days). Four subfields A, B, C and D each with separate trial. Each subfield was divided into four plots with four variants of the tillage treatment (Table 16), with two urea fertilizer treatments of (1) 0, 40, 40 and (2) 40, 70 and 70 kg/ha in the three split dressings, respectively.

Field Trial 5. Effect of the method of application of urea, two water management systems and four tillage treatments on ammonium levels of soil, on nitrogen accumulation in shoots, and on grain yields.

Autumn sowing 1969. Variety Apura (145 days). Two water management systems: in quadruplicate: (1) continuous flooding and (2) surface drainage for 4 days before and after the second and third nitrogen dressing; 8 separately managed fields. In each field four tillage treatments, wet, dry/wet, dry and zero

Table 16. Tillage on the 4 subfields (A,B,C,D) of Field Trial 4.

4A Wet tillage: *puddling intensity*	4B Dry tillage: *plowing depth*	4C Dry/wet tillage: *puddling intensity + seedbed preparation*	4D Dry tillage: *plowing intensity*
1.zero tillage	1.zero tillage	1.twice plowing + beam treatment on surface-drained field	1.zero tillage
2.2 weedcutter/ puddling operations	2.twice plowing: disc plowing harrow: depth 6 cm	2.twice plowing + beam treatment on flooded field	2.once plowing to 12 cm
3.4 weedcutter/ puddling operations	3.twice plowing: disc plowing harrow: depth 12 cm	3.twice plowing + mudroll treatment on flooded field	3.twice plowing to 12 cm
4.6 weedcutter/ puddling operations	4.1 solo track operation + twice plowing to 20 cm	4.twice plowing + twice mudroll treatment on flooded field	4.thrice plowing to 12 cm

Table 17. Urea dressing (in kg/ha) in Field Trial 5.

Surface drainage at urea dressing				Continuously flooded			
method	dressing			method	dressing		
	1st	2nd	3rd		1st	2nd	3rd
1.	0	0	0	1	0	0	0
2.on drained surface	0	50	50	2.in water	50	50	50
3.on drained surface	0	80	80	3.on leaves	0	80	80
4.in water after reflooding	0	50	50	4.in water	0	50	50
5.in water after reflooding	0	80	80	5.in water	0	80	80
6.on leaves	0	50	50	6.on leaves	0	50	50

were planned, but unfavourable weather prevented uniform treatment. Within each tillage treatment for each field, there were 6 fertilizer treatments (Table 17), which differed for the two water management systems for treatments 2 and 3. Urea was applied by hand in pellet form, except as a foliar dressing applied with a knapsack-sprayer.

Field Trial 6. Effect of nitrogen fertilization and two tillage treatments on grain yield of two varieties.

Autumn sowing 1970. Varieties Awini (125 days) and Acorni (115 days). Two tillage treatments on separate fields: (1) wet tillage and (2) dry tillage. On each field the varieties Acorni and Awini received three levels of nitrogen (Table 18) in 4 replications. Awini was sown by hand at 80 kg/ha, and Acorni at 120 kg/ha.

Table 18. Split urea dressing (in kg/ha) in Field Trial 7.

dressing	treatment 1	treatment 2	treatment 3	treatment 4	treatment 5	treatment 6
1st	0	0	40	40	0	40
2nd	0	60	0	60	60	60
3rd	0	60	60	0	60	60
4th	0	0	0	0	40	0

Table 19. Split urea dressing (in kg/ha) in Field Trial 6.

Dressing treatment 1			Dressing treatment 2			Dressing treatment 3		
1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
0	0	0	0	60	60	40	80	60

Field Trial 7. Effect of systematic omission of one of the four nitrogen dressings and of four tillage treatments on nitrogen accumulation in shoots.

Autumn sowing 1970. Variety Apura (145 days). The four tillage treatments wet, dry/wet, dry and zero were on separate fields. Each field included identical nitrogen distribution treatments (Table 19) in six replications. Shoots were sampled in duplicate.

Field Trial 8. Effect of the distribution of two rates of nitrogen between split dressings and of two soil treatments on grain yield of three varieties.

Autumn sowing 1970. Varieties Apura (145 days, 5 subfields), Awini (125 days, 3 subfields) and Acorni (115 days, 4 subfields). With seed rate of 90, 80 and 100 kg/ha, respectively, a separate trial was set out with identical treatments for each variety. Each included two soil treatments (1) dry tillage resulting in a clod structure and (2) dry tillage followed by intensive puddling with one stalkcutter and several mudroll operations resulting in a mud structure. Each subfield included both soil treatments once. Each soil treatment included the nitrogen dressing treatments listed in Table 20.

Field Trial 9. Effect of seedbed preparation on grain yield in large fields.

Spring sowing 1969. Variety Apura (145 days). After wet preparation of the tilled layer, two wet seedbed operations were compared in four pairs of 72-ha fields: (1) with a beam and (2) with a mudroll. The grain yield was estimated by combine-harvesting and by the normal procedure.

Table 20. Split urea dressing (in kg/ha) for different varieties in Field Trial 8.

Variety Apura										Varieties Awini and Acorni			
treatment	dressing				treatment	dressing				treatment	dressing		
	1st	2nd	3rd	4th		1st	2nd	3rd	4th		1st	2nd	3rd
1	0	40	80	0	13	60	30	30	0	1	40	40	40
2	0	80	40	0	14	30	60	30	0	2	60	60	0
3	40	0	80	0	15	30	30	60	0	3	0	60	60
4	80	0	40	0	16	0	60	30	30	4	60	60	60
5	40	80	0	0	17	0	30	60	30	5	90	90	0
6	80	40	0	0	18	0	40	40	40	6	0	90	90
7	40	40	40	0	19	40	90	50	0	7	0	0	0
8	40	60	60	0	20	40	50	90	0	8	0	40	80
9	0	60	120	0	21	0	90	50	40	9	0	80	40
10	0	120	60	0	22	0	50	90	40	10	40	0	80
11	60	60	60	0	23	40	70	70	0	11	80	0	40
12	0	90	90	0	24	0	70	70	40	12	40	80	0
										13	80	40	0
										14	60	30	30
										15	30	60	30
										16	30	30	60
										17	0	120	0
										18	20	20	20

4 Land preparation

4.1 INTRODUCTION

In the Wageningen Project of Surinam, practices of land preparation differ from those elsewhere in the country. The project covers 10.000 ha and uses heavy equipment. Despite those differences from medium-scale rice farming, the effects on the soil are similar. The aspects of the land preparation practices of the Wageningen project will be described in this chapter.

4.1.1 Definitions

Land preparation is the management of the soil after harvest until sowing of the new crop. It includes stubble treatment, soil tillage and field trenching.

Soil tillage includes tilled layer preparation and seedbed preparation. Tilled layer preparation is defined as the process of loosening and mixing of the soil, and of incorporation plant debris. Seedbed preparation includes mechanical weed killing, slight covering of plant debris, and flattening of the soil surface. It is mostly just before sowing.

Tilled layers and seedbeds can be made in wet or dry soil. Dry preparation is defined as the preparation of a dry surface-drained soil; wet preparation refers to flooded soil. Combinations are possible:

wet tillage comprises preparation of a wet tilled layer and a wet seedbed
dry/wet tillage comprises preparation of a dry tilled layer and a wet seedbed
dry tillage comprises preparation of a dry tilled layer and a dry seedbed
zero tillage comprises an absence of tilled layer and seedbed

The combination wet tillage/dry seedbed preparation does not occur. The others are summarized in Table 21.

4.1.2 Implements

The used equipment had only a secondary influence on results. The same results could be obtained with other implements. The implements used in the

Wageningen Project and in the trials are described below. They tend to be heavier than those used elsewhere in Surinam with equal success.

Dry tillage : two operations with a Rome offset-disc-plowing-harrow (TCH 24/24, TEH 28/22); one operation for seedbed preparation with a large wooden beam on dry soil;

Dry/wet tillage : two operations with a Rome offset-disc-plowing-harrow (TCH 24/24, TEH 28/22) on dry soil; one operation with a mudroll on flooded soil for seedbed preparation;

Wet tillage : two to four operations on flooded soil with weedcutter or stalkcutter; one seedbed operation with a large beam or a mudroll;

Zero tillage : no soil handling.

For fuller descriptions, see Table 22. For former practices see Table 23, Fortanier (1962); van der Broek (1969) and van Dijk (1971).

Most machines were drawn by caterpillar tractors; only the rotary mower was operated by a wheel-tractor. Recently, large-wheel tractors have been introduced for tillage. On Medium farms (1.4) all land is prepared with wheel-tractors with similar implements.

Table 21. Diagram showing the combinations of treatments in land preparation.

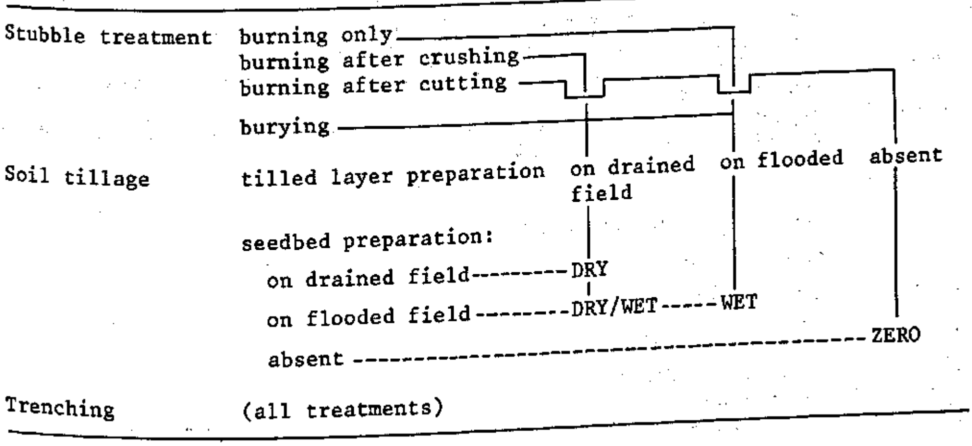

Table 22. Implements used in the Wageningen Polder

For puddling:

Mudroll: 600 kg, 1 section, working width 350 cm, roll diameter 100 cm (open), soil contact 12 gauge railway tracks 2.5 cm high 7 cm base width, home-made model with 2-3 iron rings on which narrow-gauge railway tracks were welded.
Weedcutter: 420 kg (650 kg when filled with water), 3 sections, working width 450 cm, roll diameter 50 cm (closed), soil contact 8 knives, model Marden TS.
Stalkcutter: ca 450 kg, 1 section, working width 180 cm, roll diameter (closed), soil contact 5 knives 13 cm high.

For plowing:

Offset-disc-plowing-harrow model Rome, types TCH 24/24 + Caterpillar D4C or Hanomag K7 (for first plowing), TEH 32/24 28/22 for 2nd; TCW 32/24; TCW 36/24 + Caterpillar D5SA; STCH 224/24 + International 4100.

For seedbed preparation:

Mudroll (see puddling) + 5 m x 2 cm x 15 cm piece of wood, 10-16 m (30 cm x 30 cm) wooden beam.

For mechanical trenching:

Home-made trench wheel. (Fig. 16)

Table 23. Implements used in the past in the Wageningen Polder.

For plowing:	
1950-1960:	McCormick International No 98 disc-plow (3-5 discs) for first treatment, Ramsomes Baron and Baronet disc harrow for second treatment; seedbed preparation with land-plane.
1960-	Rome-offset-disc-plowing-harrow, TCH 24/24 for first treatment, TEH 28/22 for second.
1968-	High-powered tractors also allowed the use of TCW 32/24, TCW 36/24, TCF 48/24 and STCH 224/24.
For puddling:	
1950-	Stalkcutter; weedcutter Marden T5; home-made mudroll.
For mechanical trenching:	
1968-	Home-made trenchwheel.
For seedbed preparation:	
1950-	Home-made mudroll.
1950-1967	Land-plane.
1969-	Home-made wooden beam.
Tractors:	
1950-	International TD 9 about 50 h.p. International TD 91.
1959-	Caterpillar D4C about 50 h.p.
1962-	Hanomag K7, air-cooled, 2 cylinder.
1964-	Hanomag K7, water-cooled, 4 cylinder.
1967-	Caterpillar D4D, D5SA; International 4100 wheeltractor 116 h.p.

Figure 6 gives the main differences between tillage equipment (for further data see Table 22.

For puddling or preparation of a wet tilled layer, the mudroll, the weed-cutter and the stalkcutter are used. They are all chainpulled. Both cutters have transverse knives, but the cylinder on which the knives of the weedcutter (Fig. 7) are mounted limits penetration depth; on the stalkcutter (Fig. 8) they are attached to an open frame that allows deeper penetration into the soil. The mudroll (Fig. 9) can also be used in seedbed preparation, but its working depth is limited by its lower weight and the presence of narrowgauge rails instead of knives. The rails are 2.5 cm high and have a base 7 cm wide preventing deeper penetration into the soil. The actual working depth also depends on soil properties, water depths and driving speed and other factors. Working depth increases in the sequence: mudroll weedcutter-stalkcutter.

The weedcutter is most often used. When the field is soft, the mudroll can be more efficient. Large amounts of unburnt stubble and straw are handled with the stalkcutter. On medium farms, a mounted set of discs is used.

For plowing or preparation of a dry-tilled layer an offset-disc-plowing-harrow was used (Fig. 10); on medium farms, it is replaced by a disc-plow in combination with a wheel tractor.

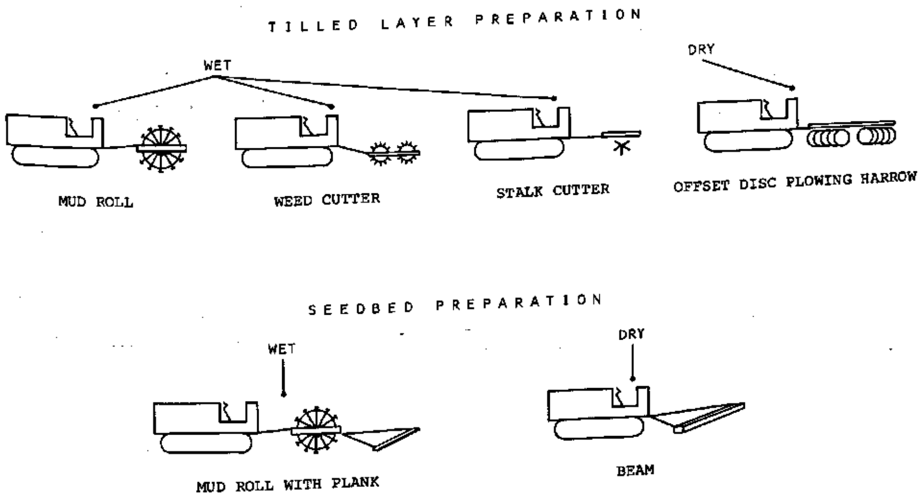

Figure 6. Implements for tillage.

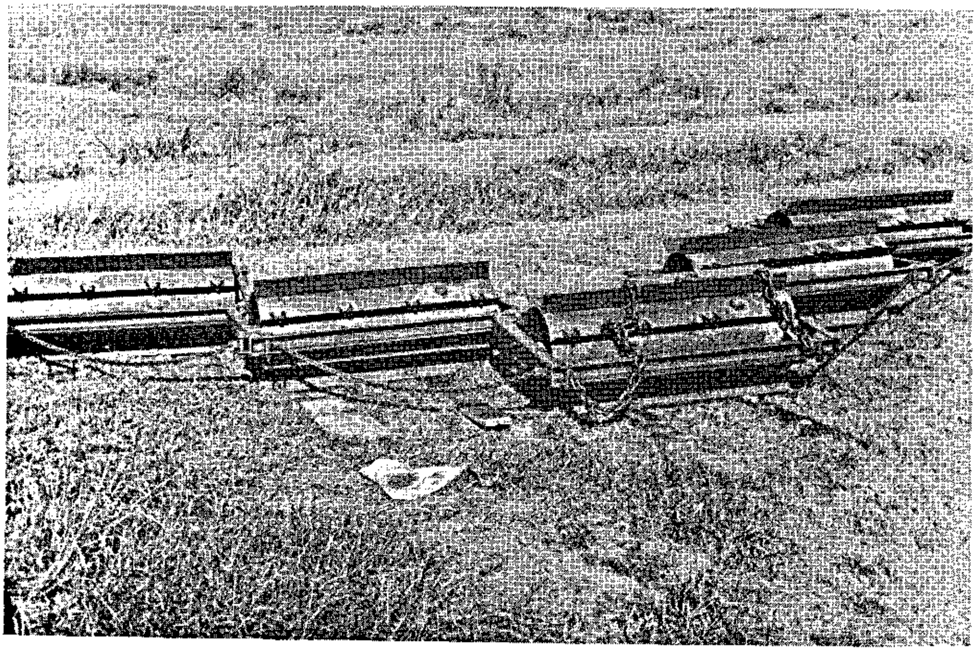

Figure 7. Weedcutter, used in stubble treatment and common in wet tillage.

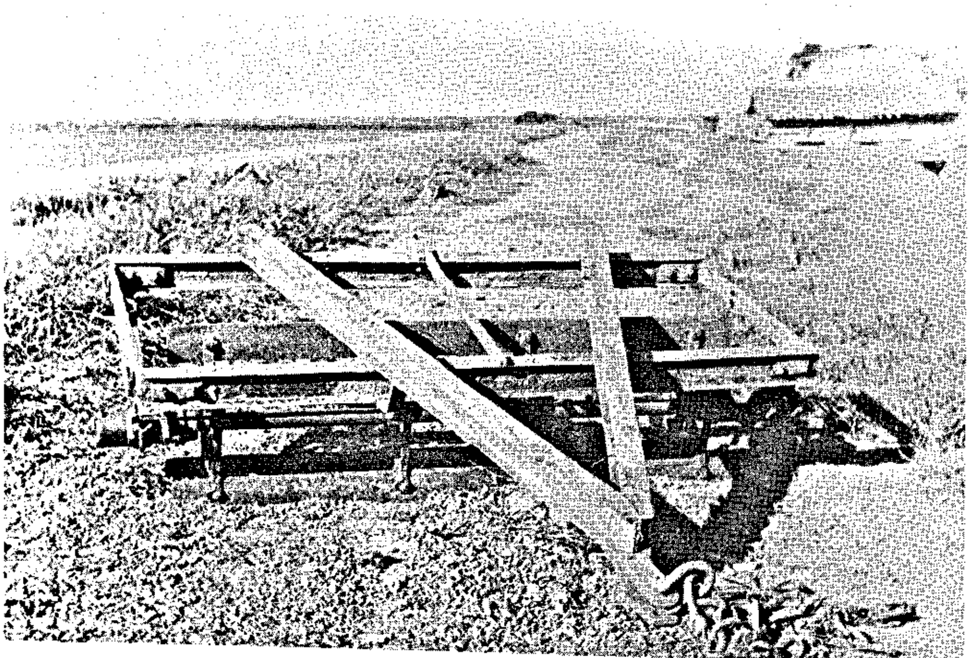

Figure 8. Stalkcutter used in wet tillage if there are large amounts of stubble to be incorporated.

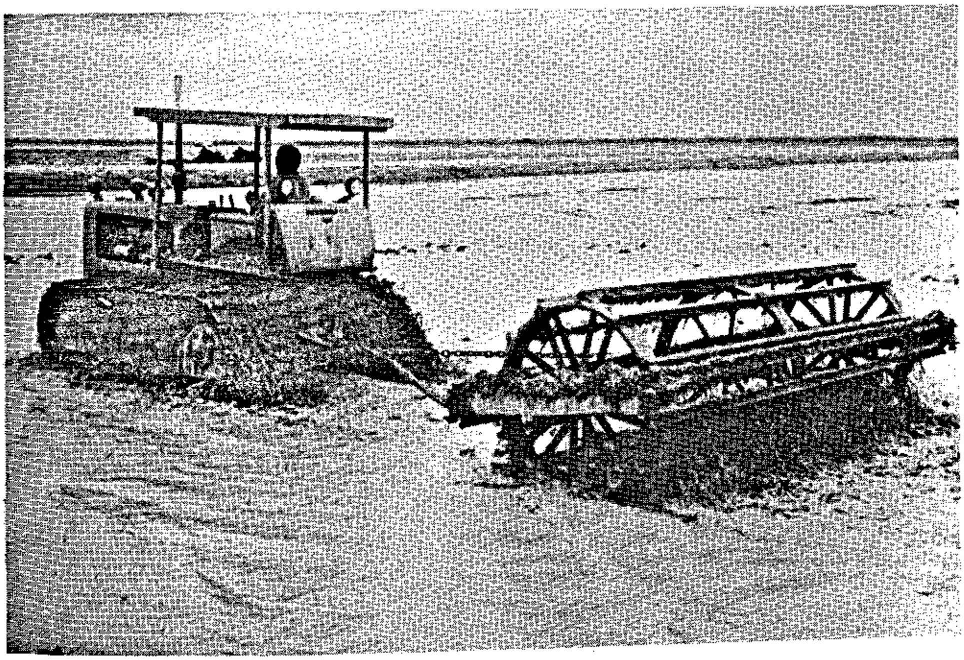

Figure 9. Puddling with a mudroll in wet seedbed preparation with dry/wet tillage.

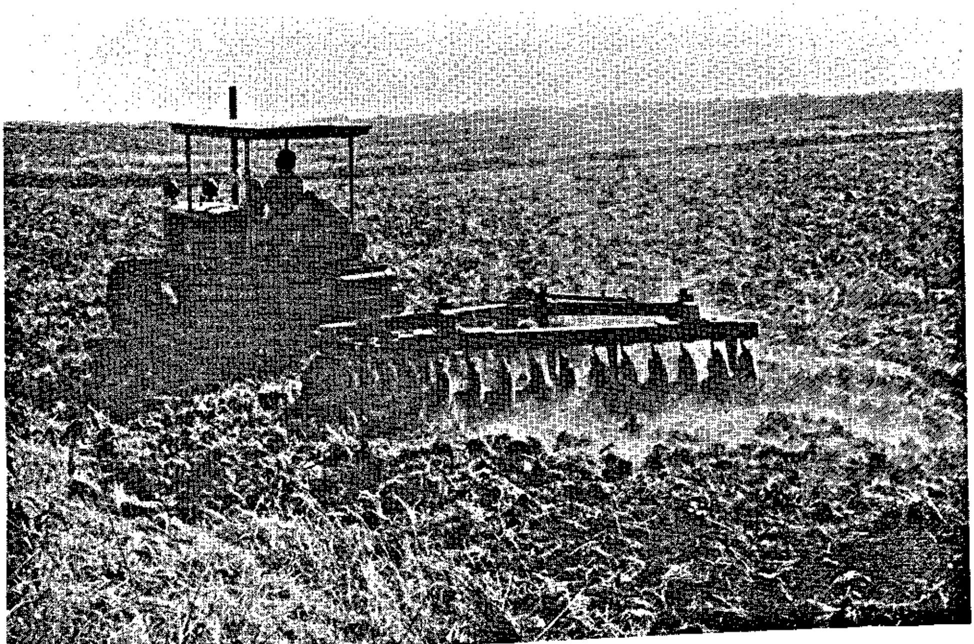

Figure 10. Plowing with an offset-disc-plowing-harrow in dry tilled layer preparation with dry tillage.

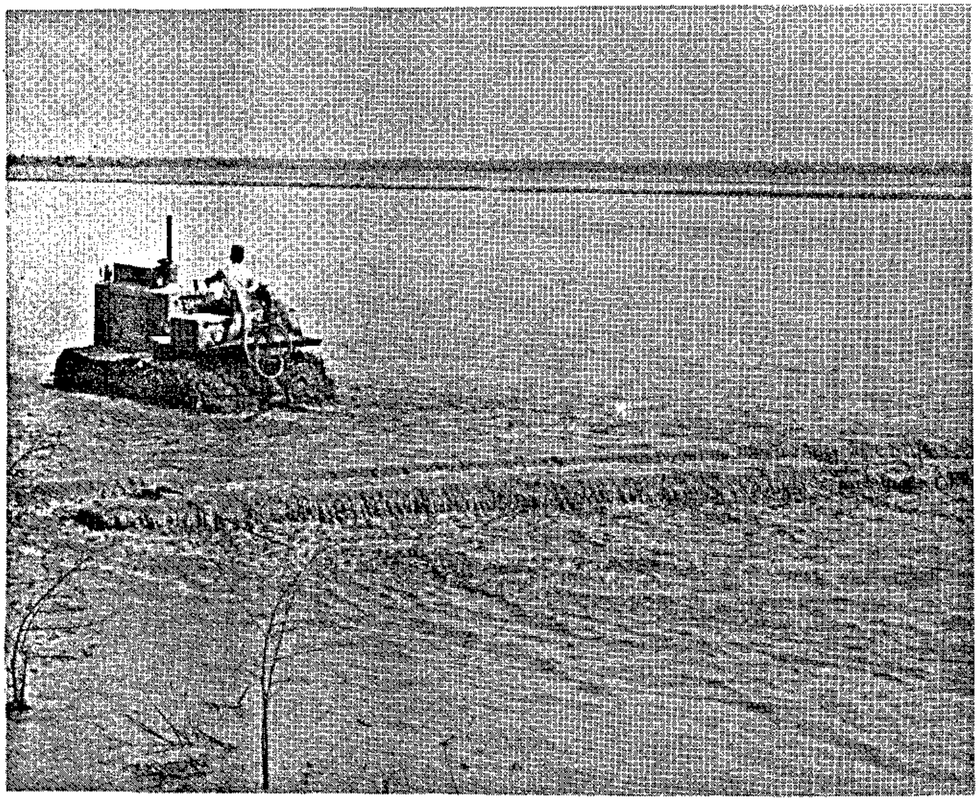

Figure 11. Seedbed preparation with a large wooden beam in a flooded field with dry/wet tillage.

For wet seedbed preparation on flooded fields, a mudroll or a large wooden beam (Fig. 11) is used. With a mudroll, puddling is slightly more thorough. The great working width of the beam promotes flattening; its intensity can be influenced by tilling the implement. Water depth much influences the effect. After wet-tilled layer preparation a 16 x 0.2 x 0.2 m beam was used, after dry-tilled layer preparation a heavier one was preferred (8-16 x 0.3 x 0.3 m). The heavy 16 m beam could be drawn by two caterpillar tractors, the lighter 16 m beam by one.

For dry seedbed preparation on drained fields, only the heavy beam was used. Fields are trenched with the trench wheel (Fig. 16). Its U-shaped wheel, mounted on the drawbar of a bulldozer, moves from out of the ditch. The upward movement of the pressed-out soil was counteracted by a cylinder extending 40 cm beyond the wheel; a transverse tine or cam on this cylinder made mini-trenches through the slightly heightened and compressed trench walls (4.5).

4.1.3 The time factor

With large-scale farming and a double cropping system, the intercrop period available for land preparation is limited. Its lenght varies between 35 and 65 days, according to rice variety. At Wageningen, increasing use is made of plants with medium growth duration (115 days), those ripening slower (over 135 days) narrow the intercrop period too much.

Of this period available for land preparation, the stubble treatment needs 10 days, mechanical trenching and snail control some 5 days, leaving only 20 to 50 days for tillage (tilled layer preparation and seedbed preparation).

4.1.4 Pre-stubble treatment period

Two weeks before harvest, the surface of the field is drained by parallel ditches and temporary trenches (4.5). As an almost impermeable layer at 15-50 cm blocks subsoil drainage, almost all water has to be removed superficially to ditches 100-200 m away (1.5). Weather and crop transpiration determine how much disappears by evapotranspiration. Varieties with a long growth period are almost entirely yellow after wet and dry/wet tillage but keep their green colour much longer after dry or zero tillage and so transpire more; varieties with a short growth period stay green till the harvest under all tillage treatments. The moisture level of the soil also depends on the history of tillage (6.1.).

The small-scale unevenness of the soil surface after dry tillage results in tiny pools between the clods which can disappear only by evapotranspiration and not by surface drainage.

Soil drying in the pre-harvest drainage period increases the soil bearing capacity. The bearing capacity is also related to the structure of the tilled layer. At the end of the cropping season, the bearing capacitv increases from dry, dry/wet, wet and zero tillage. Low bearing capacity of the soil at harvest causes the combine tracks to sink 20 cm into the soil and form tracks. In extreme cases, the combine gets stuck in the field, by soil clogging to the track-laying mechanism. Flooding the field is then necessary to facilitate self-cleaning of the tracks. Deep tracks block surface drainage, collect rain and are almost impossible to drain due to their irregular depth.

4.2 STUBBLE TREATMENT

Harvesting with a combine leaves a stubble 40-60 cm high with rows of threshed straw on top. Both have to be removed by burning or burying to facilitate tillage and to promote the establishment of the pre-germinated seed. Where no tillage is applied, only burning is practiced[1].

Stubble can only be completely *buried* during wet tilled layer preparation. After a fallow period the amount of plant material is much lower and can be buried by plowing. The stubble is partly incorporated in the tilled layer and partly covered by the sespended part of the soil, which settles out as a sedimentation layer on top of it.

I did not check how much time it takes between burying and decomposition, but Williams (1957) has shown (in California) that nitrogen is not immobilized under anaerobic conditions. Little energy is gained during decomposition in the several stages compared with that from almost complete decomposition under aerobic conditions. Hence, micro-organisms grow and multiply little, and take up little nitrogen from the soil. In practice, flooding for three weeks is sufficient but five weeks is better. This "incubation" period is assumed to be related to the increase in electrolyte concentration in the soil solution at the start of the reduction process. Weeds also need some time to rot far

[1] When the stubble is left on the field, part of it starts to rot after flooding and is carried by the prevailing wind to one of the corners of the field. It is deposit at drainage on the seedbed, endangering the establishment of young plants. In addition, it may block drainage pipes.

enough to avoid weed regrowth after drainage of sown fields.

Disc harrowing buryes the straw insufficiently to obtain a clean surface; the same holds for slight puddling at seedbed preparation after dry tillage. Dry tillage is hampered by the presence of stubble and straw. Fields can be disc-harrowed only if the stubble has not yet been cut or crushed, when the plants still stand upright. If stubble is cut and crushed, and rain prevents subsequent burning, disc-harrowing is impossible. Especially when the soil is still moist, it clings to straw and stubble, and clogs the disc-harrow.

Disc-ploughing instead of harrowing may sufficiently bury the stubble. This method is not used in large-scale farming but can be profitable on a small scale.

Commonly straw and stubble are *burned*. Under unfavourable weather conditions this is possible only with the loose combine-threshed straw on top of the stubble, even if the stubble is buryed by puddling afterwards. For a more complete burning, the stubble has first to be treated with a weedcutter or rotary mower.

The weedcutter crushes straw, accelerates drying. In addition, stubble is compacted to a mat, that burns easier. The soil surface has to be dry, otherwise the stubble will be pressed into the soil or will stick to it, hampering drying. Normally burning is possible seven to ten days later.

The rotary mower cuts off all the stubble, accelerates drying and allows burning after two days. This burning is more complete after cutting than after crushing.[1]

Complete burning encourages drying of the soil. A mat of partly burned stubble and straw acts as a cover, obstructing the entry of air and diminishing evaporation. In general, the need for thorough stubble burning decreases with a more intensive incorporation of stubble by tillage in the sequence zero, dry, dry/wet and wet tillage.

Figure 12 shows the course of the stubble treatments. Absence of burning (1) needs complete burying by puddling. Only burning loose straw also needs it (2). In such cases, plowing with the offset-disc-plowing-harrow is mostly not possible, but a disc or mould-board plow can be used if the stubble is not crushed or flattened into a mat. Burning the straw after crushing or cutting (3) facilitates plowing with the offset-disc-plowing-harrow. Zero

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[1] The weedcutter is drawn by a caterpillar tractor; the rotary mower by a wheel tractor. The latter needs a more evenly dried surface because it tends to stick in soft spots.

tillage (4) is, as a rule, practiced only after cutting and complete burning.

The outcome of a stubble treatment is influenced by soil conditions and precipitation in the pre-stubble treatment period (4.1.4). Rainfall and uneven drying of the field limits the mechanical treatment of the stubble. If there is heavy rain after crushing or cutting, puddling is necessary as drying takes too long.

The farmers aim at dry or dry/wet tillage, where tillage is rather easy. So he tries to get rid of stubble and straw by burning as quickly as possible after crushing or cutting. He will only use wet tillage if he is forced by weather conditions. This may occur even after he has removed the stubble already by burning. Zero tillage is not practised, except in trials.

4.3 PREPARATION OF TILLED LAYER

The limited available time for soil tillage is determined by the fixed sowing date in the double-cropping system. Although it takes more time, plowing is preferred to puddling (and zero treatment). Plowing is, however, only possible on a dried soil. When time is too short or weather is unfavourable to obtain a dried soil, the field must be puddled.

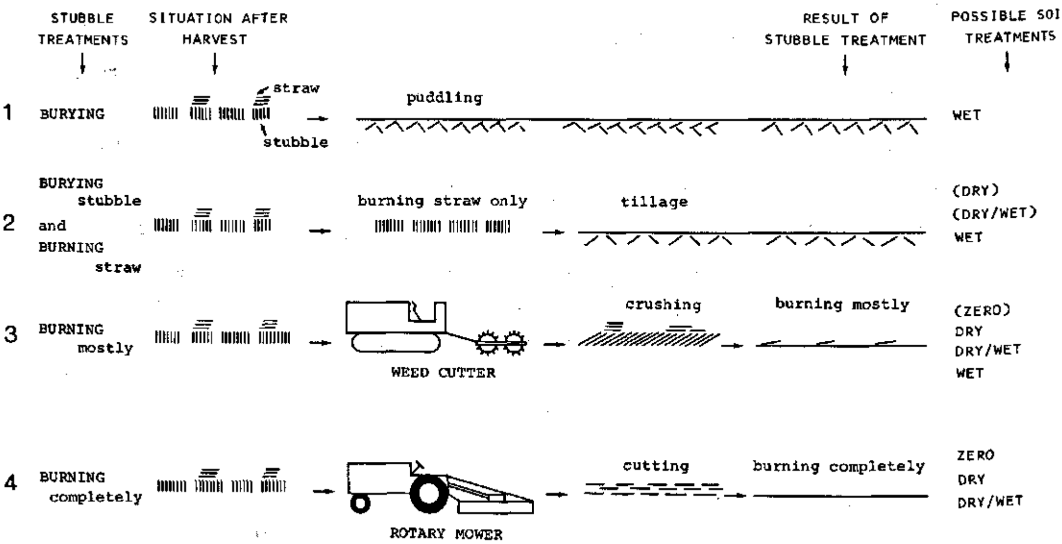


Figure 12. Course of stubble treatments.

Plowing or disking with the Rome offset-disc-plowing-harrow is wholly dependent on weather and soil. This is easier than puddling, the costs are less, sinking into the soil and repairs cause less trouble, and grain yields are higher. But it takes at least 10-14 days after harvest for the soil to dry sufficiently for the first dry plowing. The length of this period is increased if it rains. The clods need 3-7 days more to dry before the next plowing can reduce clods further.

The moisture range in which dry plowing is practised runs from 45 % (w/w) moisture (sticky point) to 35% (lower plastic limit). These limits are determined in kneaded soils. Previous drying of the soil causes cracking and increases the maximum moisture content for plowing to 50%. Unevenness after plowing is correlated (r = +0.78) with moisture content (Fig. 13). The roughness R = 100 S characterizes this unevenness where S is the standard deviation of the needless of a relief meter with 20 needles in 30 measurements on one field (Kuipers, 1957).

The first plowing cuts off the contact between the clodded topsoil and subsoil. Thereafter the topsoil can dry to below the shrinkage point. Without clodding this does not happen under normal field conditions, where upward capillary transport of water results in a moisture content of at least 35%. After the first plowing, clods start to dry and their reduction in size after the second plowing results in a decrease in moisture content down to 8%.

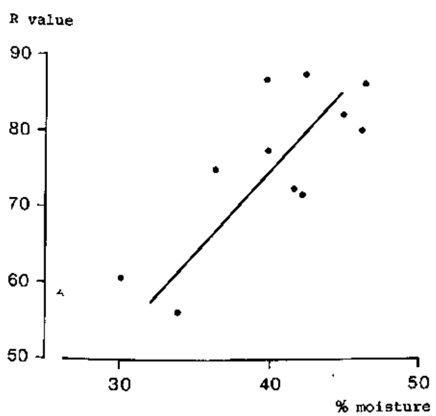


Figure 13. Influence of moisture content at plowing on roughness of soil surface (after van der Broek, 1968).

When the soil is too wet during first plowing, the clods tend to become as hard as concrete and cannot be reduced in size unless a second plowing follows within three days.

If it rains hard after the first plowing, a second plowing is impossible and the clods have to be reduced by puddling. This type of tillage is intermediate between dry and dry/wet; it was not included in the trials. If the clods have not sufficiently dried after first plowing, it is advisable to continue drying as far as weather and time permit, even with water at the bottom of the tillage layer.

The course of treatments during land preparation and water management is shown in Figure 14. The time needed from first plowing to sowing is at least 14 days, to allow time for drying of the clods and for seedbed preparation. A further five days of submergence before sowing is needed for snail control (1.5.).

Puddling is practised when plowing is impossible. The length of flooding needed to wet the soil before this treatment can start, is up to 7 days depending on the previous dryness of the soil. The preparation of a wet-tilled layer can be finished in one or two days on a soft soil, but it may take up to seven days before the tilled layer is formed when the soil is hard and difficult to penetrate.

Puddling is possible with a mudroll, a weedcutter or a stalkcutter. Their working depths and intensities increase in the order given but are influenced by soil conditions and water depth. The weedcutter is used most frequently for puddling in tilled-layer preparation. When the field is soft, the mudroll can be more efficient. Large amounts of unburnt stubble and straw are handled with the stalkcutter.

The number of treatments depends on the consistency of the soil: the softer, the fewer. But the more stubble to be incorporated, the more treatments are needed. In general, the number of treatments is between 2 and 5. Each treatment increases puddling depth because the caterpillar tractor sinks deeper and deeper into the soil (Fig. 15).

Zero tillage is uncommon. Obviously it needs perfect stubble burning, an even surface, absence of weeds, and sufficient water for 20-30 cm deep inundation.

Unevenness due to previous tillage makes fields unsuitable for zero tillage. The same applies to land with heavy growth of young weeds that cannot be

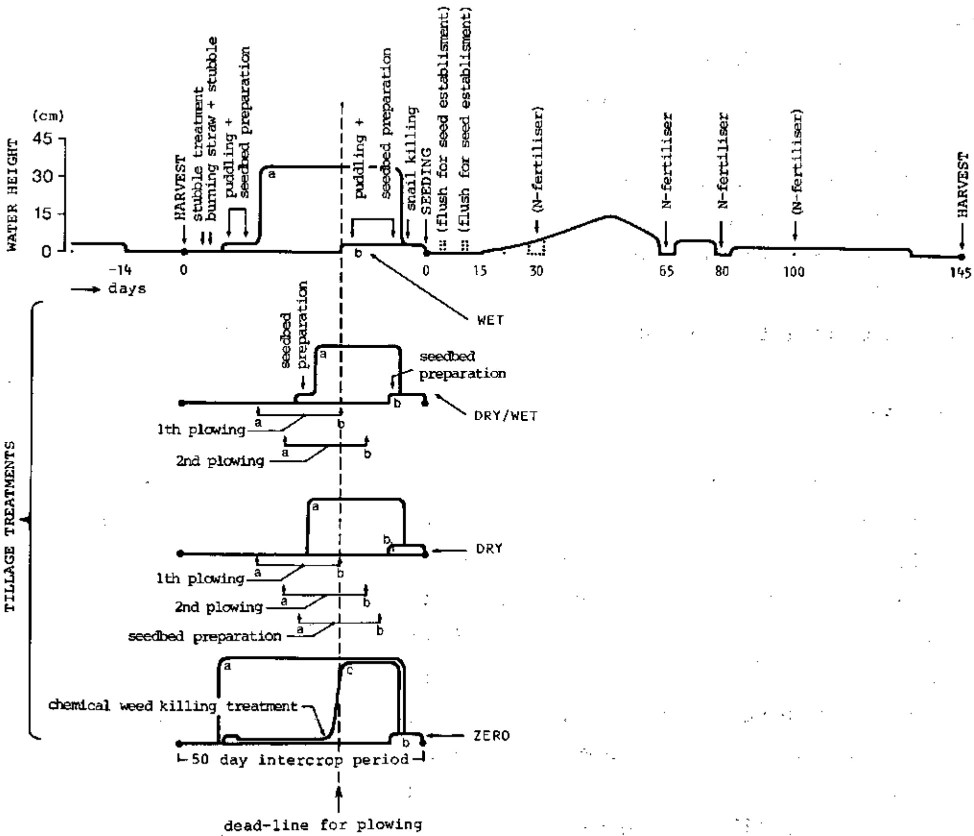


Figure 14. Water management during tillage and the growing period.

Legend

	water management (in brackets: optional)
a, b, c:	extremes of water management possibilities at different tillage treatments
wet :	2-4 operations on inundated soil with weedcutter or stalkcutter followed by one seedbed operation with a large beam or a mudroll
dry/wet:	2 operations with an offset harrow on dried soil an 1 operation with a mudroll on inundated field for seedbed preparation
dry :	2 operations with offset harrow and 1 large beam operation for seedbed preparation on dry soil
zero :	no soil treatment

killed by chemicals. Heavy weed growth can be avoided by flooding for 1-2 weeks to shallow depth. Such a period causes weed seeds to germinate and the seedlings can be chemically treated before they are too old (2-3 leaves). Deep flooding then promotes rotting.

Otherwise, tillage moves most of the weed seeds downward whereas (pre-soaked) rice seeds are in the more favourable position at the surface. A rice seedling needs a start over the weed seeds to control weeds (1.5.). With zero tillage, chemical control of weeds needs more accurate timing as the advantage of the rice seeds over the weed seeds is less than with other tillage treatments.

4.4 SEEDBED PREPARATION

Seedbed treatment includes the removal of weeds and plant debris, and the flattening of the surface, to encourage seed establishment and crop growth.

Flooding, in combination with the use of a weedcutter, mudroll or beam causes most weeds to die and covers the debris with a mud layer. In this procedure, a weedcutter is most efficient if weed growth is heavy. The use of a beam on a surface-drained dry-plowed soil has little effect on weed growth.

For flattening, the beam is most suitable (followed by the mudroll and the weedcutter), mainly because of its working width. After dry plowing, without puddling, the beam is most successful unless many weeds are present.

Puddling in tilled-layer preparation may cause the tractors to sink too deep, especially when the field has not much dried after the harvest. To

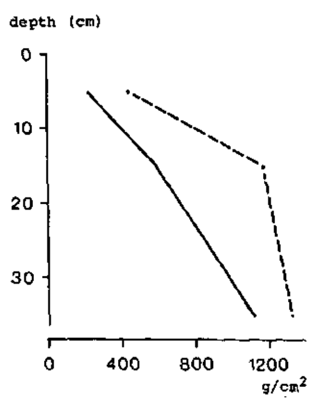


Figure 15. Penetrometer pressures after inundation (after van der Broek, 1968). —— inundated and thrice puddled; --- inundated, not puddled afterwards.

prevent this, the seedbed can be prepared immediately after tilled-layer preparation, when swelling is limited. Deep flooding can then suppress weed growth.

Dry seedbed preparation promotes surface flattening but only slightly affect weed growth nor bury plant debris. The drying of the soil in the preceding dry plowing is effective in killing the root system of pernicious weeds.

Rice seeds falling in the open water of small pools often die. This is often accompanied by a bluish violet iron film on the water surface after dry tillage. Beam treatment of the drained surface can remove unevenness.

4.5 TRENCHING

The drainage system in the Wageningen Polder consists of open primary, secondary and tertiary canals emptying into the Nickerie River (partly by pumping). Connected to this system are ditches (that can be closed) 100 to 200 m apart and 600 m long, draining fields of 6-72 ha. Each rice growing season, temporary trenches about 25 cm deep are made with a trench wheel mounted on the drawbar of a caterpillar tractor running from ditch to ditch (Fig. 16).

After sowing, remaining low spots are connected to a ditch or a trench, by handtrenching, to allow complete surface drainage. This surface drainage system promotes pre-emerged seed establishment and fertilizer efficiency, and eases combine-harvesting.

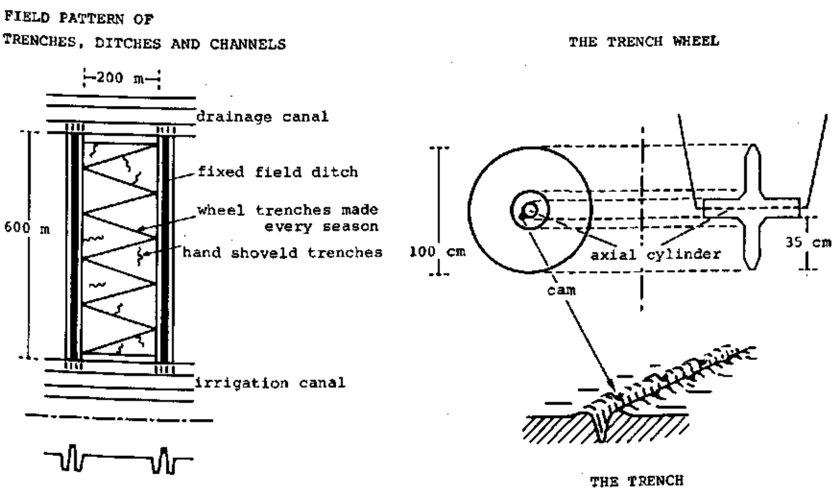


Figure 16. Mechanical trenching with trenchwheel.

4.6 CLIMATIC ASPECTS

Land preparation measures, especially soil tillage is limited by weather conditions. As drainage through the soil is zero, all superfluous rainwater has to evaporate or to be removed by surface drainage before dry tilling is possible.

Figure 17 shows that only during the months March/April and September/November low rainfall is preceeded by a period with a high percentage of sunshine, as is needed for the ripening of the seed. Consequently the harvest periods are March/April and September/October.

In the Wageningen Polder, water management and harvest need a period of 7-9 weeks ('harvest periods' in Fig. 17). For varieties with a long growing period, dry tillage is then almost impossible. For varieties with a medium growth period, some 120 days, dry tillage is more possible, especially in the long dry season from September/December, but in the short dry season from February/April, land preparation has to be extended to the beginning of the wet season, whereas incidental high rainfall makes dry tillage impossible then.

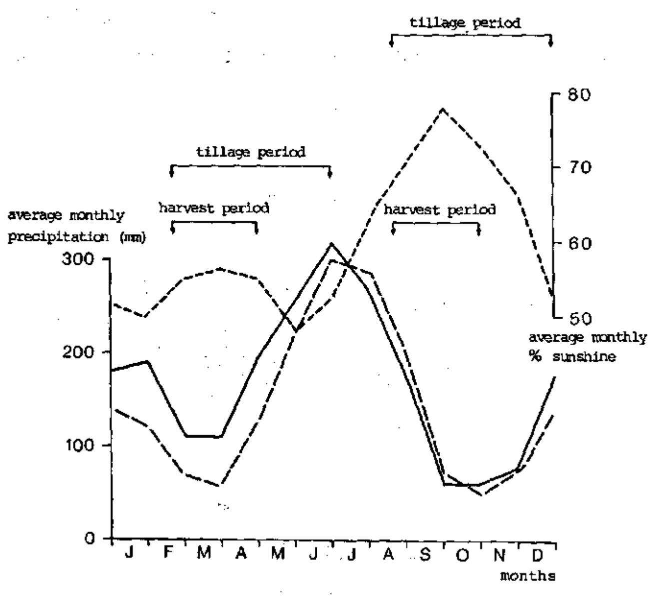


Figure 17. Harvest and tillage period in relation to rainfall and sunshine. - - - average monthly sunshine percentages, Nickerie, 1931-1960; ——— average monthly precipitation, Nickerie, 1931-1960; — — — average monthly precipitation, Wageningen, 1928-1967.

The picture is complicated by large variations in the start of the rainy season and by rain in the dry season. Figure 18 shows the chance of no rain for 6-10 and for 10 days in every 10 days, after subtraction of 5 mm per day for evaporation. The same procedure has been followed with an assumed evaporation of 3 mm per day.

The influence of the daily evaporation in the range 3-5 mm is low. As expected, the long dry season is more favourable for dry tillage than the short dry season which is usually impractical for plowing. The short rainy season may even be absent, which means that the dry season is extremely dry; mostly this accompanies a late start to the long rainy season. If so, dry tillage in the 'short' dry season is justified.

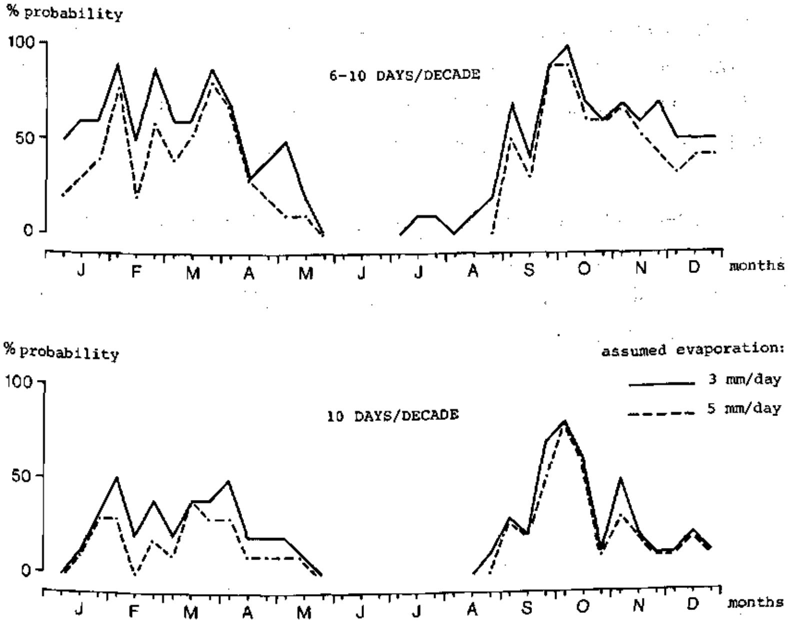


Figure 18. Probable number of days without rain per ten days available for soil drying and dry tillage at Wageningen Polder 204H, 1958-1967; assumed evaporation ——— 3 mm per day; assumed evaporation - - - - 5 mm per day.

SUMMARY CHAPTER 4

1. Land preparation is defined as the period from harvest to sowing of the new crop. In double cropping of rice, in the Wageningen Polder it includes stubble treatment, tillage and field trenching.
2. Stubble treatment includes burning or burying the stubble. Burying is by puddling. Burning the loose combine-harvested straw is possible without further treatment. Standing stubble has to be crushed with a weedcutter or cut with a rotary mower to allow drying of the stubble and compacted to allow burning.
3. Tillage is defined as preparation of a tilled layer and of a seedbed. Both can be on a drained or a flooded surface, defined as dry and wet preparation, respectively.
   wet tillage includes preparation of a wet tilled layer and a wet seedbed;
   dry/wet tillage includes preparation of a dry tilled layer and a wet seedbed;
   dry tillage includes preparation of a dry tilled layer and a dry seedbed;
   zero tillage includes an absence of preparation of a tilled layer and of a seedbed.
4. Land preparation, especially soil tillage is restricted by weather conditions in Surinam. The probability of dry weather, favouring dry and dry/wet tillage, is low in the short dry season (February/April) and higher in the long dry season (September/December).

5 Morphological aspects of soil

5.1 INTRODUCTION

The main purpose of my investigations was to find a relation between tillage methods and grain yields. Obviously, any such a relation is indirect: tilling affects certain soil properties and these influence plant development. Consequently the discussion below will first pay attention to the effects of tillage on the soil (Chapters 5, 6 and 7) and afterwards to the relations between soil and plant growth (Chapters 8, 9 and 10).

The soil characteristics are classed into morphological, physical and chemical aspects. Morphological aspects include the mechanical influence of tillage on soil structure and breakdown in the tilled layer. Physical aspects include soil moisture (water content, moisture potential and permeability) and structural stability. Chemical aspects include changes in soil nitrogen and components of soil moisture.

The four main tilling categories have been discussed in 4.1.1:

(1) wet tillage is puddling and results in mud;
(2) dry/wet tillage includes dry plowing and puddling, resulting in mixed clods and mud;
(3) dry tillage is dry plowing and results in clods;
(4) zero tillage

Section 1.3 gave general macromorphological descriptions of representative soil profiles. Morphological differences between the soil treatments were not observed below the tilled layer. Hence the description in this section is almost restricted to this layer. For superficial structure at the surface, see 8.2 (Figs. 55-57).

For a further study of the morphology of the soils, samples for thin sections were collected from sites treated in four ways for three successive seasons. Samples were taken at depths of 0-5, 1-16 and 15-30 cm at the beginning and end of the growing season: (1) three weeks after seeding and (2) two days after harvest (3.1). The thin sections have been described by van Mensvoort (1973).

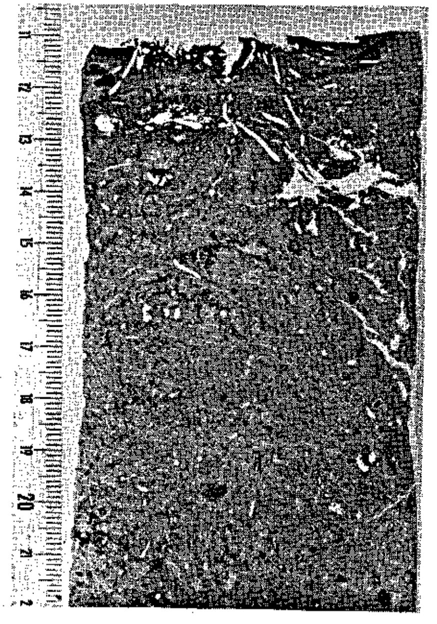


Figure 19. Wet-tilled soil,0-15 cm depth. The soil is compact, with a sedimented layer and some large holes associated with incorporated stubble residues. The dotted lines indicate residual sedimented layers from previous seasons.

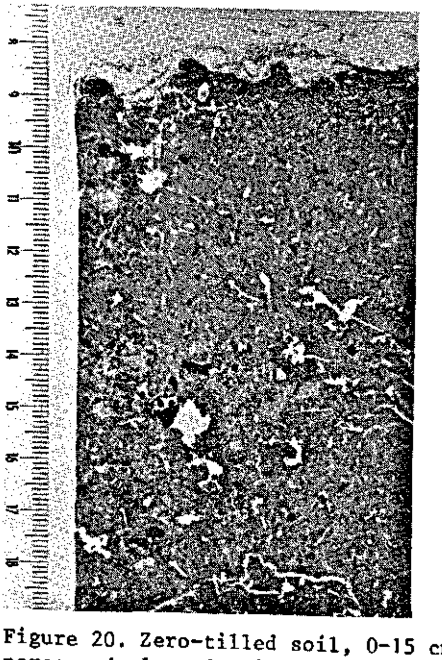


Figure 20. Zero-tilled soil, 0-15 cm depth, with many small and interconnected pores and plant debris on the surface.

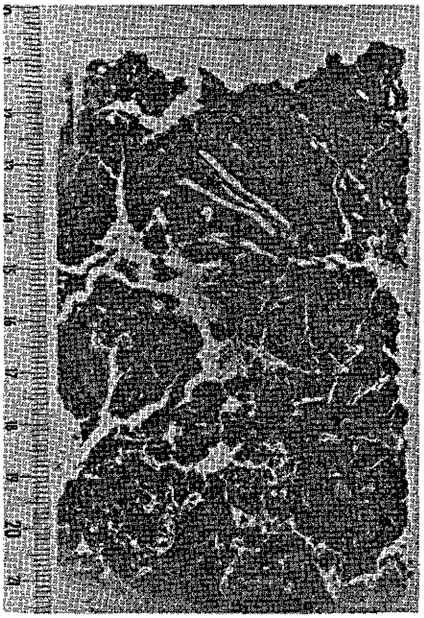


Figure 21. Dry-tilled soil, 0-15 cm depth, with some large and many small clods and three large root channels from a previous season (upper centre).

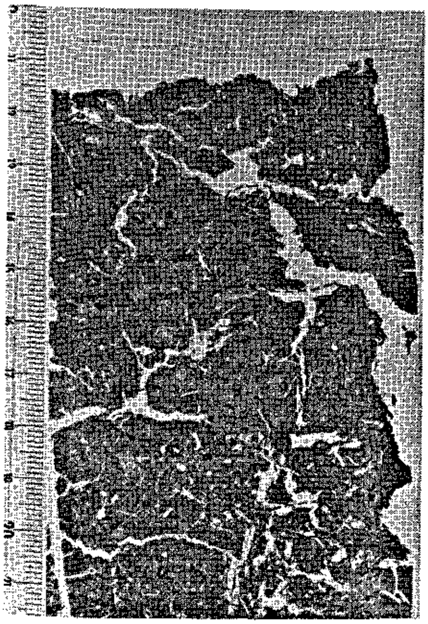


Figure 22. Dry/wet-tilled soil, 0-15 cm depth, with many recent sedimented layers inside the tilled layer (indicated by dotted lines).

The influence of tillage on soil structure is partly mechanical, partly a combination of physical, chemical and microbial effects. Purely mechanical are changes in the spatial arrangement of the soil particles, finding expression in the occurrence of voids, clods, sedimented layers, the breakdown of soil fragments, and stress phenomena. The combined physical, chemical and microbial effects refer to the occurrence of cutanic features and organic matter, and its decay.

Thin sections of soils after wet and zero tillage had a compact structure with only a few large cavities, and pores consisting of channels and vughs (Fig. 19 and 20). With zero tillage, the absence of mechanical loosening left a compacted structure as apparent from bulk density (6.2), but this was only slightly discernible in the thin sections. Dry and dry/wet tillage showed recently formed clods (Fig. 21 and 22); dry tillage resulted in a rather loose arrangement of clods. With dry/wet tillage, this looseness was absent as the openings between the clods were filled by puddling, resulting in rather large strongly packed elements with few gaps.

Wet and dry/wet treatments resulted in a sedimented layer in the upper part of the tilled layer, being more pronounced after wet tillage. Dry/wet tillage also resulted in a sedimented layer between the larger clods in the tilled layer; after zero treatment it was almost absent; after dry tillage completely absent (5.4).

Only dry tillage caused a change in spatial arrangement with time. Here the samples collected in the first part of the growing season had a few large clods and many small ones loosely packed together. They had irregular surfaces. At the end of the growing season, the surfaces of the larger clods had smoothened and there were fewer very small clods.

5.2 CAVITIES

Cavities (voids) included channels (e.g. root channels), vughs (irregular isolated oval cavities) and planes. Packing voids were absent. Channels 5 - > 400 µm wide occurred in all treatments. Vughs also occurred after all treatments but were more frequent after dry and dry/wet tillage.

Differences in the cavities between soil treatments were most evident in the planes:

After dry tillage, there were many craze planes connected with macropores (> 4000 µm). They occurred on the clods and their surfaces were irregular. At the end of the growing season, there was some redistribution, resulting in smooth surfaces. Connected with pores 200-2000 μm wide were a few skew planes.

After dry/wet tillage, there were some craze planes, with rather smooth surfaces connected with smaller pores (2000-4000 μm across), but they were less frequent than after dry tillage.

After wet tillage there were no craze planes and only a few skew planes.

After zero tillage, the situation was the same as after wet tillage.

In the sedimented layer resulting from puddling, pores were absent, except those caused by plant roots. After drying, cracks gave some other passages. With wet tillage, transport through the lower part of the tilled layer was also severely restricted. The same, though to a lesser degree, was true of dry/wet tillage. Zero tillage produced a pattern of many profusely interconnected small pores. After dry tillage, large interclod pores improved water transport.

5.3 CUTANIC FEATURES

Cutans were absent in the tilled layer, but subcutanic features were common. The occurred as iron oxide accumulations in the soil mass (ferrans) adjacent to channels, vughs and planes (neoferrans) and at some distance from these voids (quasiferrans).

For neoferrans the treatments resulted in differences in their frequency, thickness, colour intensity, and association with channels, vughs or planes.

Frequency and intensity of vughs and plane neoferrans increased in the order wet--zero--dry/wet--dry. This order was correlated with the occurrence of cavities. Plane neoferrans were typical of dry tillage, being thick there (1 to 4.8 mm). They increased only there in intensity and thickness during the growing season. Channel and vugh neoferrans did not increase in size during the season in any soil treatment.

A special surface plane neoferran was present in the sedimented layer after wet and dry/wet treatment. It was orientated along the strata of this layer.

Table 24. Properties of channel neoferrans in the tillage treatments.

Tillage	Frequency	Thickness (μm)	Contrast	Boundary	Colour intensity
wet	many	80-1500	very distinct	sharp or diffuse	++++
dry/wet	many	80- 500	distinct	sharp or diffuse	++
dry	many	50- 150	faint to distinct	diffuse	+
zero	many	5- 30 75- 500	distinct	sharp or diffuse	+++

They occurred as iron oxide accumulations in the soil mass (ferrans), adjacent oxidize along stratification lines.

Channel neoferrans were common in all treatments, but they look different for each tillage method (Table 24).

Dry tillage causes a enormous increase in area of contact between floodwater and soil because of to the clod formation. Both during flooding and drainage, and soil because of the clod formation. Both during flooding and drainage, though the neoferrans still increased in thickness from some 1 mm to 3-5 mm. Wet and zero tillage did not show any such phenomena.

5.4 SEDIMENTED LAYER

The sedimented layer (Fig. 23a and b) originates from soil material brought into suspension by puddling. This material settles according to particle size and density: accumulations of clay plasma and coarse organic matter first, then the smaller particles, so that the size of particles of the organic matter decreased upward and in the upper 50 µm of the sedimented layer microscopically visible organic matter was nearly absent: this layer consisted almost entirely of fine clay particles, which after drying were densely packed.

The fine texture of this clay (with 85% of the particles < 16 µm and 3% > 50 µm) prevents a clear stratification in the settling. On the surface, fresh plant material, mainly rice leaves, accumulated. In the sedimented layer, an irregular band rich in iron, 500 µm thick (dry/wet) to 1000 µm thick (wet), runs parallel to the surface. Narrow bands with rather highly concentrated iron, 50-100 µm thick, occurred inside it. With zero treatment, these layers were not discernible.

Three types of sedimented layers have been distinguished in Table 25.

Table 25. Type of sedimented layer occurrence

occurrence in tilled layer	age	occurrence at tillage treatments			
- at the surface	recent	wet	dry/wet		(zero)
- below surface, top of clods	recent		dry/wet		
- below surface, not oriented	residual from previous seasons		dry/wet	(dry)	(zero)

The sedimented layer *at the surface of the tilled layer* (Fig. 23a and b) is due to tillage in stagnant water. Its thickness depended on the puddling intensity and varied from 2-5 mm (dry/wet) to 9-17 mm (wet treatment). The plasma of this layer had an omnisepic plasmic fabric tending to a unistral plasmic fabric. The clay domains in its upper part were almost all oriented parallel to the soil surface and contrasted with the soil mass, though the common boundary was faint. With zero tillage, the action of raindrops and air explosion at flooding resulted in such a sedimented layer only here and there, but it was thin: after three seasons of zero treatment only 0.5-1 mm. A peaty layer of plant debris and partly burned stubble also accumulated, but it was so thin that it was lost in preparation of thin sections.

The sedimented layer *horizontally orientated inside the tilled layer* (Fig. 24) occurred only after dry/wet tillage. The suspended material resulting from slight puddling enters the tilled layer through openings between the clods and sediments there locally. They were 1.2-3 mm thick and did not contain any coarse organic matter. The iron band was thinner (50-100 μm).

Residual sedimented layers from previous seasons were most distinct in the dry/wet tillage treatment.These residues could only be distinguished from the soil mass by their regular strata or organic matter particles and by the orientation of the plasma but not if they were at the surface or on top of clods in the tilled layer. They were up to 17 mm thick, round to oval; their contrast with the soil mass was faint to distinct; their boundary was faint; the distribution was random. They occurred inside clods or soil mass, but not on top of clods. The residues were present in all treatments, except wet tillage. With dry and zero tillage, they were formed three season or more ago, they looked old, being affected by different processes and showing breakdown and intersection by channels. Despite their greatest formation with wet tillage, the residues were absent through complete destruction by the next puddling treatment. Dry plowing only cuts up and mixes the sedimented layer throughout the tilled layer, without much destruction. This effect caused the residues to be most abundant with dry/wet tillage, as the sedimented layer was formed every season, with limited destruction at the next tillage in the slight puddling of the top of the clods only.

5.5 ORGANIC PARTICLES

Organic matter and its distribution were estimated by counting organic particles in thin sections with a 3 mm grid. In Table 26, the values were

Figure 23A.

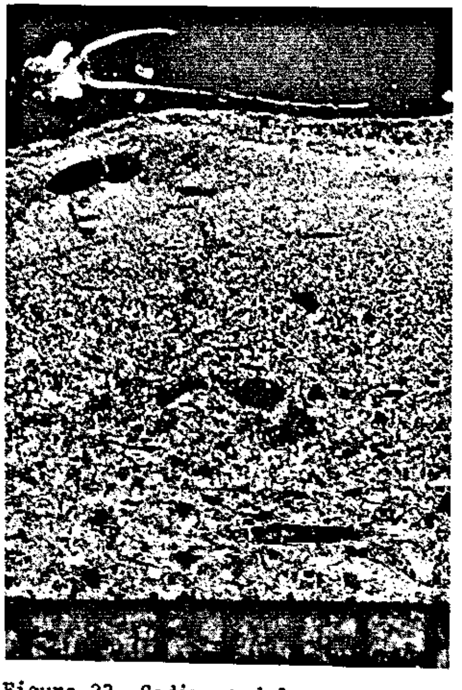


Figure 23B.

Figure 23. Sedimented layer at the surface of the puddled tilled layer with wet tillage. A. By crossed polarizers. B. With normal light.

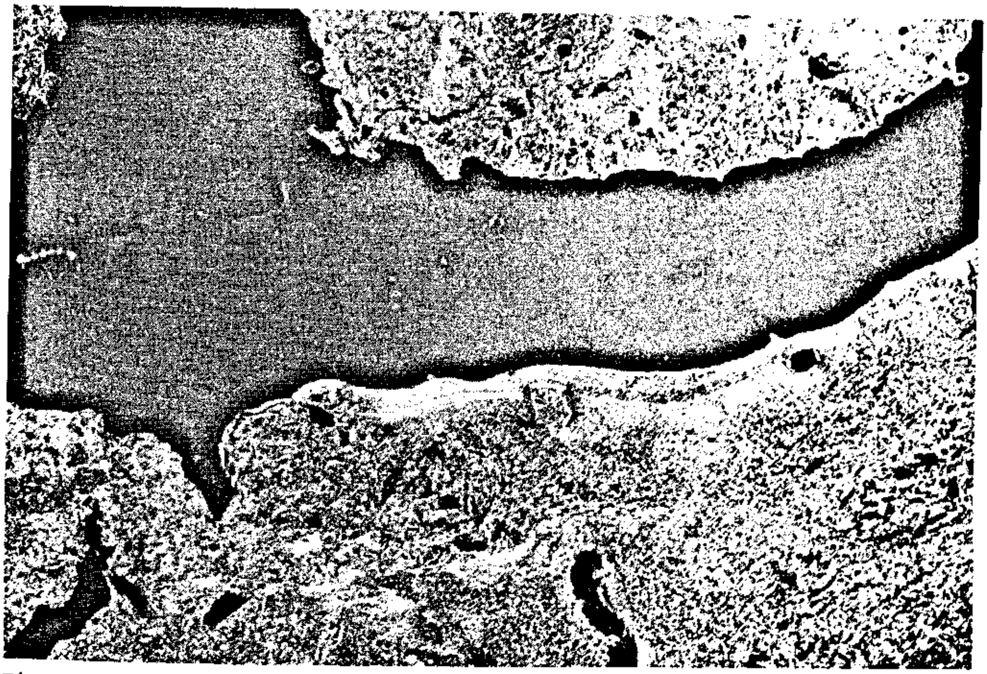


Figure 24. The sedimented layer inside the tilled layer on top of clods with dry/wet tillage by crossed polarizers.

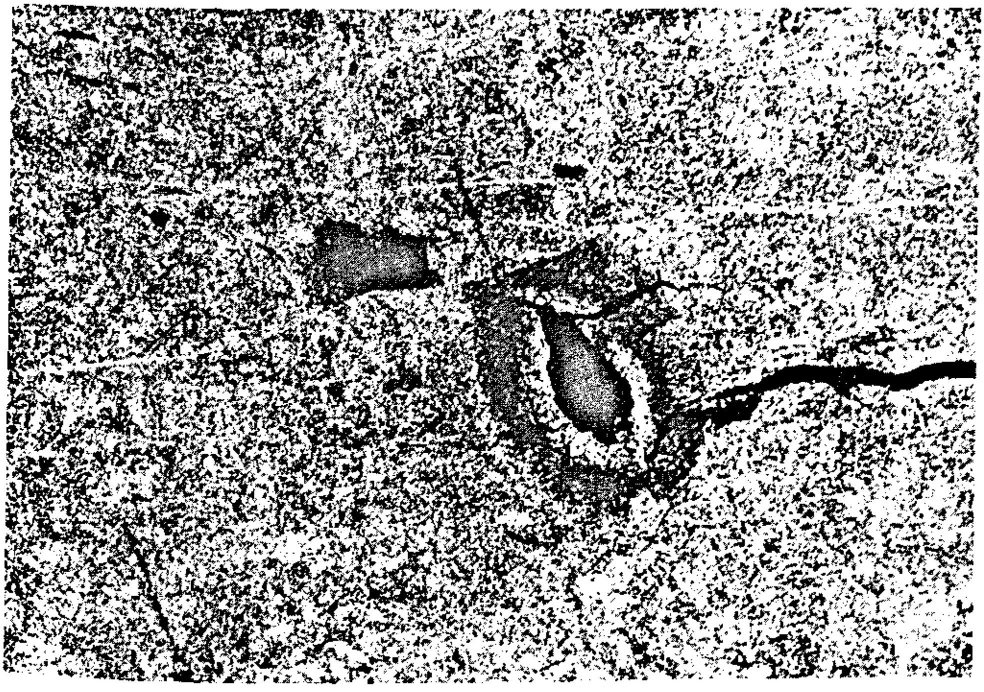


Figure 25. Stress phenomenen in the soil below the tilled layer. A neo-ferran has been transported intact along a pressure line.

Table 26. Volume percentages of organic matter as related to soil depth, tillage and sampling date

Tillage	Organic matter				Increase in organic matter in top 5 cm during growing season
	start of growing season depth		end of growing season depth		
	0-5 cm	0-15 cm	0-5 cm	0-15 cm	
wet	15.1%	12.9%	19.6%	12.6%	4.5%
		16.5%			
dry/wet	16.9%	11.9%	21.8%	15.8%	4.8%
		14.3%			
dry	13.9%	12.9%	16.0%	10.8%	2.1%
		12.3%			
zero	17.3%	17.5%	19.7%	15.0%	2.4%
		17.5%			

The least significant (van der Plas, 1965) differences vary from 2.4 to 3.7.

expressed as volume percentages (Chayes, 1965).

The results show that in all tillage treatments, the organic matter increases in the upper 5 cm during the growing season. This was a seasonal effect because, at the start of the growing season, the differences between the content of organic matter in the top 5 cm and the top 15 cm did not differ much for each soil treatment. The increase in organic matter was small for zero and dry tillage, relatively large for wet and dry/wet tillage.

After the growing season, the increase in organic matter slackened because of shrinkage of plant material by drying, distribution over the whole tilled layer, and breakdown.

During the growing season content of organic matter in the top 15 cm decreased in all treatments, except dry/wet tillage. As these values included the increasing values of the top 5 cm, the decrease for the 5-15 cm layer must be much higher. Probably the increase in organic matter from root residues was counteracted by their mineralization (partly due to tillage) and to the reduction of the particles to too small a size for counting. Indeed tillage tended to diminish the size of organic matter particles (Table 27).

Breakdown of organic matter was visible in percentages of organic matter particles > 50 µm being lower with tilled soil than with zero tillage. In the tilled soil, puddling tended to be more effective in reducing particle size below 50 µm.

Table 27. Percentages of organic matter particles >50 µm.

wet tillage	dry/wet tillage	dry tillage	zero tillage
37.8	38.4	38.7	41.1

Duplicate countings in samples taken at start of rice-growing season.

5.6 FRAGMENTATION OF SOIL PARTICLES

The fragmentation or wearing down of soil particles by tillage was studied for pegasse (peat) residues and subsoil fragments. The pegasse particles were mainly from the peat layer on the virgin soil before reclamation twenty years ago. The subsoil fragments were characterized by a low content of organic matter and a uniform plasma orientation and tended to show unistral lines extinguishing in polarized light. They were mixed with the tilled layer by previous rather deep tillage.

Both kinds of fragments were counted in the same way as organic matter but were expressed per profile area. Below 1 mm^2, the subsoil fragments could not be distinguished and, though the pegasse residues could, this limit was established for both. The results are in Table 28. Obviously the fragments were most common and largest with zero treatment; wet treatment was intermediate; values were least with dry/wet treatment.

Table 28. Breakdown of organic matter in the top soil by tillage.

Tillage	Subsoil fragments >1 mm^2		Pegasse fragments >1 mm^2	
	average size		average size	
	(mm)	(%,v/v)	(mm)	(%,v/v)
dry	4.4	0.68	1.72	0.58
dry/wet	2.9	0.46	1.52	0.41
wet	6.6	1.26	2.35	1.07
zero	5.0	1.95	3.77	1.87

Data from thin sections of samples taken at the beginning of the rice-growing season.

The mechanical action of tillage largely influences the breakdown of pegasse residues and subsoil fragments. Dry plowing much more effectively cut the remains to pieces less than 1 mm thick than did puddling. Combined plowing and puddling had only a slight effect. Organic matter of the fraction < 50 µm increased more with puddling than with dry plowing (5.5) contrary to fragments > 1 mm discussed before. This will be due to differences in microbial activity in the breakdown of small particles. Microbial life was more intense after puddling, as also obvious from increased nitrogen mineralization (7.1); it seemed to increase after drying of the soil before flooding. These changes will be partly due to the mechanical action of puddling, which promotes the removal of small particles from the countable sizes.

5.7 STRESS PHENOMENA

The subsoil below 15 cm was not often sampled and no differences between tillage treatments coul be established. Stress phenomena in the form of pressure planes and plastic flow were abundant.

Plastic flow occurred mainly along pressure planes, which could be easily recognized by their masapic fabric. The main pressure planes were at 30 ^{o} angle to the surface and were connected by many small and short pressure planes in all directions. The transported plasma was deformed to different degrees: Figure 25 shows part of a hardly altered neoferran.

Pressure planes are somewhat more frequent in the 5 cm below the tilled layer than further down.

5.8 GENERAL DISCUSSION ON SOIL MORPHOLOGY

Micromorphological features allow a better understanding of the physical and chemical data to be treated in the next chapters.

Some of them, such as voids and sedimented layers, indicate the spatial arrangement of the particles in relation to transport phenomena, in which the voids are possible paths for transport. With wet tillage, these paths were narrow and uniform, their connections were few, and the sedimented layer restricted the vertical transport of the floodwater into the voids. With zero tillage, the picture differed considerably: there was more connection between the pores and the barrier formed by the sedimented layer was only present here and there and then reasonably pervious. Dry tillage gave large interclod pores, allowing adequate transport in the tilled layer. With dry/wet tillage, transport was obstructed by a sedimented layer at the soil surface, the space between the large clods being filled with small fragments, and sedimented layers inside the tilled layer hampered transport.

The occurrence of neoferrans reflects the penetration of oxygen into the soil through its surface and the rice roots. During drainage periods, the soil surface is in contact with the oxygen in the atmosphere (Table 8), but during flooding only dissolved oxygen reaches the soil surface. The nature of this surface determines the contact between oxygen and soil: its area was smallest with zero or wet tillage, largest with dry tillage. With dry tillage, oxygen may penetrate large pores between the clods of the tilled layer; with wet tillage, the sedimented layer forms a barrier allowing only diffuse transport. With zero tillage, only small pores are available for the dissolved oxygen to pass to the micro-organisms within some millimeters. The situation for dry/wet tillage resembled that of wet tillage, although the slightly irregular surface made the contact area somewhat larger and the sedimented layer was less developed.

In all treatments, oxygen would penetrate the soil through rice roots. No differences in root properties were found between tillage treatments (8.3).

Differences in the type of neoferrans were assumed to be related to the compactness of the soil. With wet treatment, they were thick and distinctly contrasted with their surroundings; with dry/wet and zero treatment, they were intermediate; and with dry tillage, they were less pronounced. The increase in iron content of extracted soil moisture during the growing season (7.2) for dry tillage coincided with the increase in thickness of the plane neoferrans in that period.

The mechanical influence of tillage is shown in the description of the sedimented layers, together with counts of subsoil fragments and pegasse fragments in the tilled layer. Puddling broke up the sedimented layer at the surface most, whereas it broke down subsoil fragments and pegasse remnants less than dry plowing. With a combination of dry plowing and a slight puddling (dry/wet), the size of pegasse and subsoil fragments decreased most, whereas residues of sedimented layers were most abundant, because of their repeated formation every season with limited destruction.

The combined mechanical-microbial influence of tillage is given in the organic matter counts. With puddling, the breakdown of organic matter particles was slightly more effective than with dry plowing. The greater efficiency of puddling over dry plowing for the breakdown of pegasse and subsoil fragments is caused by the interference of microbial action and the smaller particle size.

Table 29. Review of the soil morphological features with the tillage treatments.

	Voids	Cutanic features	Sedimented layer			Fragmented pedorelicts	Change in organic matter in the top 5 cm
	craze planes	neo-ferrans	at the surface	in the tilled layer	residual		
tillage treatment							
wet	-	+++	+++	-	+	+	++
dry/wet	+	++	++	++	+++	+++	++
dry	++	+	-	-	++	++	+
zero	-	++	+	-	++	++	+

\- absent + infrequent ++ frequent +++ abundant

The quantities of organic matter in the soil expressed in volume percentages might give an idea of the organic matter production and consumption during a season. After puddling, the top 5 cm indeed show a large increase related to rapid seedling development and growth during the first half of the rice growing season (8.2). The differences in organic matter volume between the tillage treatments are of no consequence. However, those in size and volume of the pegasse residues are distinct, as confirmed by a comparable trend in the subsoil fragments. The effect of differences in tillage treatments for 3 seasons 20 years after reclamation of the swamp soil was unexpected. The predominantly wet tillage until then would have influenced fragmentation only slightly.

The stress phenomena in the subsoil indicate a compact soil. Pores are blocked and collapse by swelling of the soil, in which cracks are filled with soil fragments from above.

Table 29 gives a summary of the observed phenomena in the tillage treatments.

SUMMARY CHAPTER 5

1. The differences in soil morphology between tillage treatments are concentrated in the tilled layer. The differences are the occurrence of cavities, neoferrans, sedimented layers, organic matter particles and fragmentation of soil particles.
2. The cavities are large after dry tillage, mainly craze planes connected to clod surfaces. After dry/wet tillage, craze planes are narrower. After both

dry and dry/wet tillage, old root channels persist from the previous rice crop inside the clods. After zero tillage, cavities are frequent; they are very small but intensely interconnected. After wet tillage, many small cavities occur, which are scarcely interconnected.

3. Iron accumulations next to channels and planes occur as neoferrans with all tillage treatments. After dry tillage, they occurred on the clod surfaces in wide bands and inside the clods around channels. After zero tillage, they occurred only around channels; after wet and dry/wet tillage, they occurred in the sedimented layer at the surface of the tilled layer and around channels. The neoferrans were most pronounced in increasing order wet, dry/wet, zero and dry tillage. Only with dry tillage was an increase observed in thickness of craze plane neoferrans during the season.
4. The sedimented layer at the surface of the tilled layer averages 13 and 4 mm thick with wet and dry/wet tillage, respectively. It consists of fine clay particles only in the upper 50-100 µm and contains of organic matter particles below. A sedimented layer horizontally orientated inside the tilled layer occurs after dry/wet tillage. It does not contain coarse organic matter particles and is 1-2 mm thick. Residual fragments of the sedimented layer from previous seasons occur in all tillage treatments in decreasing frequency in the order dry/wet, dry, zero and wet.
5. During the growing season, there was an increase in volume of organic matter in the top 5 cm of the tilled layer and a decrease in the 10 cm below this layer.
6. Fragmentation of subsoil fragments and of peat residues was mainly mechanical and was most intense with dry plowing, puddling having only a slight effect. Hence the order of fragmentation by mechanical force increased in the sequence zero, wet, dry and dry/wet tillage. Break-up of soil organic particles was more intense with puddling than with dry plowing, as it involves both mechanical and a microbial activity.
7. In the layer below the tilled layer, pressure planes occurred along which plastic soil or sometimes intact soil fragments are transported, resulting in a massive layer, with hardly any cavities.

6 Physical aspects of soil

The heavy clay soil considered here contains over 85% particles < 16 μm and only a small fraction of sand (up to 3% > 50 μm). Customary mechanical analysis shows a uniform particle-size distribution through the tilled layer, irrespective of tillage treatment. As the gas content of the soil is always low during flooding, the study of the influence of tillage on physical soil properties was concentrated on soil moisture. Content of moisture and bulk density are measures of the amount of water in soil; soil moisture potential is a measure of its properties.

These potentials were measured in the field and in the laboratory. With data on permeability to water and various assumptions, a model could be built up for matrix suction and water transport. The outcome was compared with data collected in the field. Matrix potential and calculations of osmotic potential from conductivity will be given.

6.1 MOISTURE CONTENTS

Because of the high clay content, the soils strongly vary in moisture content[1]. The water management in the different tillage treatments is shown in Figure 26. The arrows in the figure, indicating the direction of flow in the soil, will be explained later (6.6).

The moisture contents in the *intercrop period* are given for the different tillage treatments in Figure 27. The flooded soil had a moisture content of 60-110%, surface drainage results in 50-70% moisture; without rain it went down ultimately to 30-40%. Only with clod formation was the moisture content of the tilled layer lowered down to 10% (Table 30).

With continued evaporation of the drained surface, the dried top layer almost blocks upward water and gas transport from below and capillary rise of water is just sufficient to replenish the small losses, despite surface cracking.

1. Unless stated otherwise, all moisture contents are expressed as weight of water divided by weight of dried soil in g per 100 g.

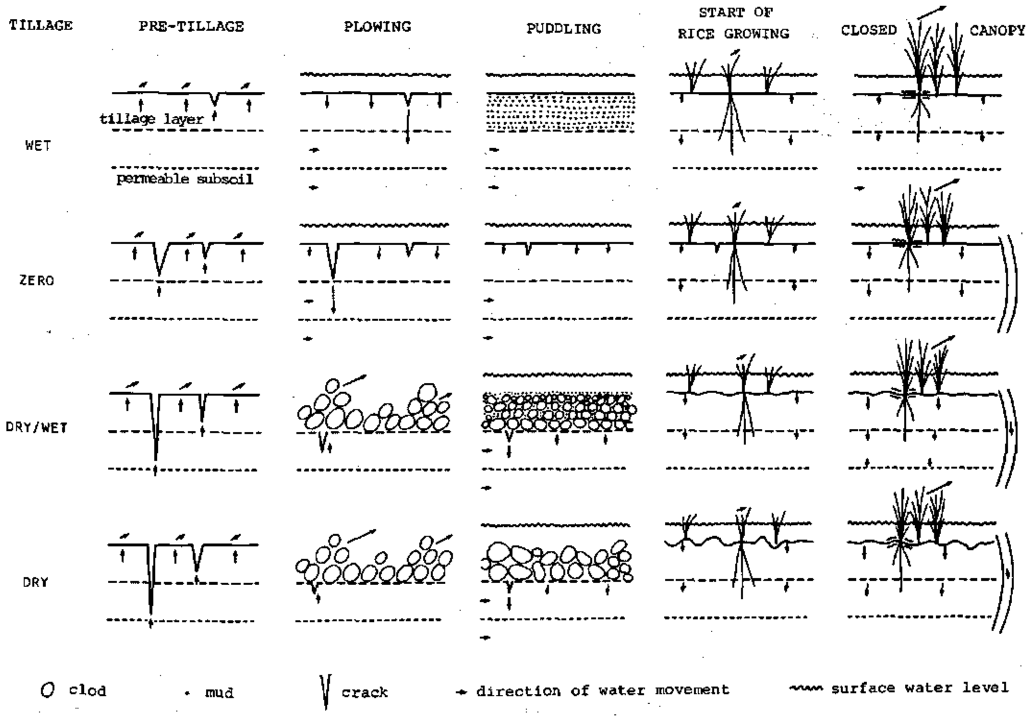


Figure 26. Water management in the tillage treatments

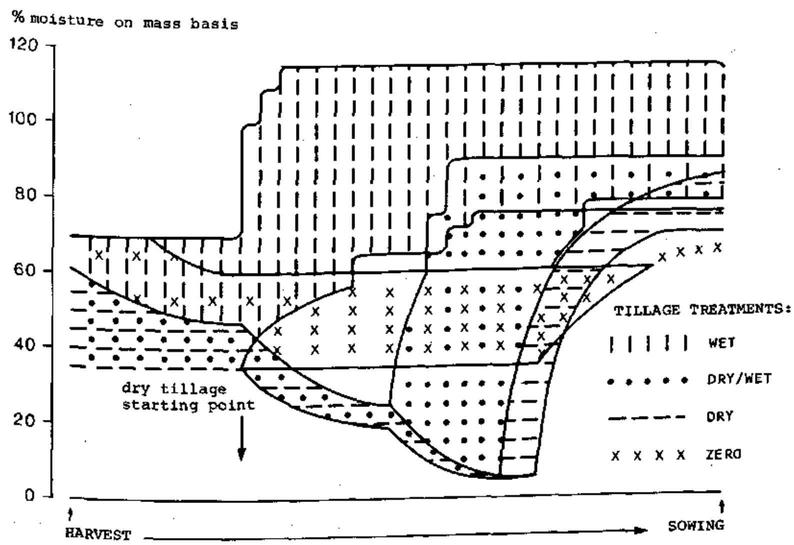


Figure 27. Changes in soil moisture in the topsoil in the tillage period

Table 30. Lowest soil moisture values on mass basis during tillage period.

Tillage	wet	dry/wet	dry	zero
Lowest moisture content	>45%	about 10%	about 10%	30-60%

Table 31. Moisture ranges during rice-growing period.

Depth	0- 5 cm	5- 10 cm	10-15 cm	15-20 cm	20-25 cm
Moisture % on weight basis	60-110	60-110	60-85	60-70	60-70
Moisture % on volume basis	45- 70	50- 70	55-70	55-65	55-65

An equilibrium is present between the supply of soil moisture from below and loss through evaporation.

After clod formation, the capillary rise of moisture is cut off. Drying of the clods results in drying past the shrinkage point and allows air to enter inter-aggregates pores. In this situation even slight rainfall may result in considerable fluctuations of moisture content. After flooding, moisture increased to 60-75%; after subsequent slight puddling before sowing, the increase was only slightly greater (to some 70-80%).

Wet tillage (puddling only) resulted in a wide range in moisture contents: 70-100%, depending on firmness of the soil, working depth of implements, and thus on the intensity with which water and soil mix.

In the top 10 cm, the moisture content after planting generally settled at 70-85%, independent of the previous treatment, though Table 31 shows that there were large variations.

The changes in moisture content *during crop growing* are given in Figure 28. After puddling, the moisture content started very high throughout the soil. In the top 15 cm, this is directly due to puddling, in the deeper layers solely to long flooding. During the growing season, the top 15 cm (and particularly the top 10 cm) tended to decrease in moisture content as a result of evapotranspiration. This decrease was irreversible and was accompanied by a change in packing of the clay particles in the mud. The result, at the end of the growing season, was an equal moisture content after wet and zero tillage in the upper 20 cm. Below 20 cm, moisture content decreased slightly after puddling in wet and dry/wet tillage, and piezometer levels decreased (6.6.2). This decrease results not from a change in structure, but partly from replacement of water by

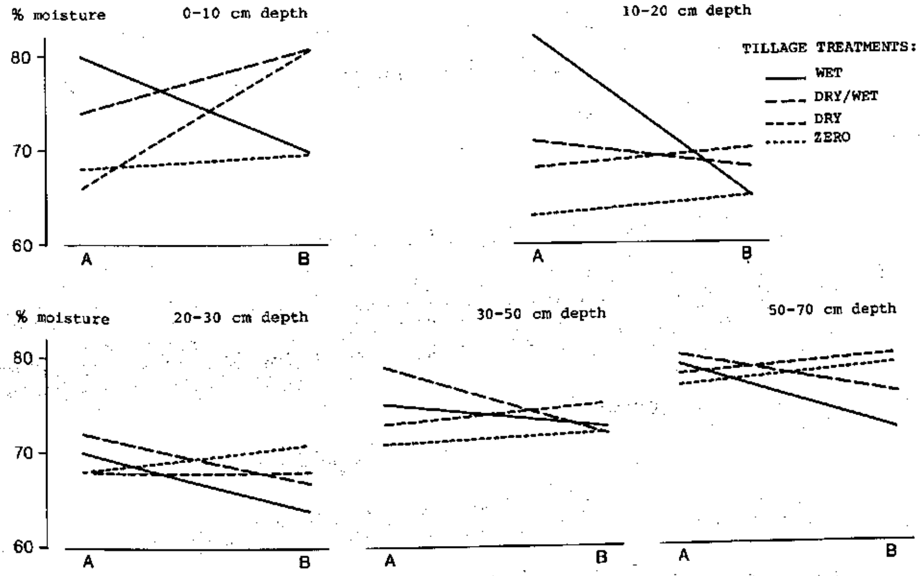


Figure 28. Changes in soil moisture during the rice-growing season. A. Three weeks after seeding. B. Four weeks before harvest.

gases, partly from increased matric suction.

After plowing, the moisture content in the top 10 cm tended to start increasing two weeks after sowing. The treatments dry and dry/wet tillage were submerged less than a week before seeding, after which they were surface-drained for two weeks. The water-saturated soil further increased in moisture content by slow expansion of the clay lattice after earlier intense soil drying.

The slow downward transport of water into the subsoil caused the moisture content to increase with the two treatments flooded latest (dry and zero) (Figure 28).

6.2 BULK DENSITY

According to Kamerling (in press), the bulk density of the soils in the lower coastal plain of Surinam is generally low. Data of the tillage treatments are given in Figure 29.

My investigations showed that in the top 25 cm variations in density with depth were larger than these induced by tillage. Tillage solely loosened the top soil and decreased the bulk density only there. Rooting and organic matter, both decreasing bulk density, were concentrated in the top 10 cm. Differences between tillage treatments occurred mainly in the top 5 cm. Ab-

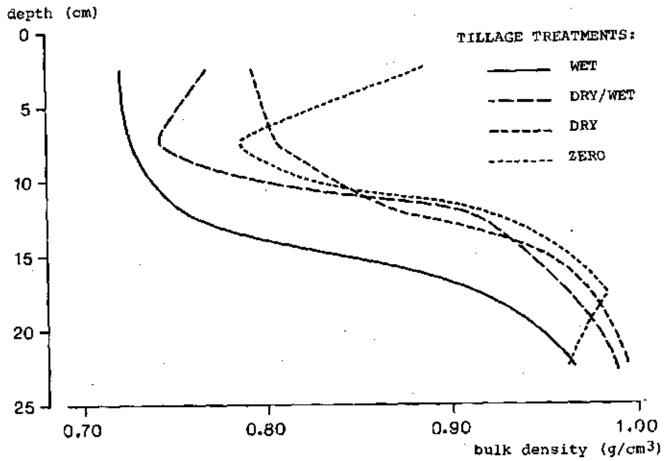


Figure 29. Bulk density during tillage of samples obtained a month after sowing

sence of soil loosening and compaction by traffic during harvesting result in higher bulk density values with zero tillage in the upper 5 cm (0.90). The lowest values (0.70) occurred with wet tillage; dry/wet and dry tillage were intermediate.

The influence of tillage on bulk density was absent below 15 cm, where it ranged between 0.96 and 1.00.

6.3 DEHYDRATION CURVES

Soil moisture, expresssed as a weight or volume percentage, refers to the amount of water present in the soil. Dehydration curves indicate the gradual release of the soil moisture with increasing suction. Figure 30 gives those for the various tillage treatments, for which the samples were collected in the field. The pF range up to 2.7 was investigated. The release of soil moisture up to pF 2.7 was minimal at depths below 15 cm in the soil. In the tilled layer, the release of soil moisture increased in the order zero-dry-dry/wet-wet. The dehydration curves vary widely in the tilled layer and indicate the destruction of soil structure by puddling during wet tillage and the compaction with zero tillage.

The puddling treatments, wet and dry/wet tillage, showed a relatively high release of water in the top 5 cm in the pF range 2.0-2.3, which is related to the sedimented layer (5.4). Compaction of the top 5 cm is indicated by the

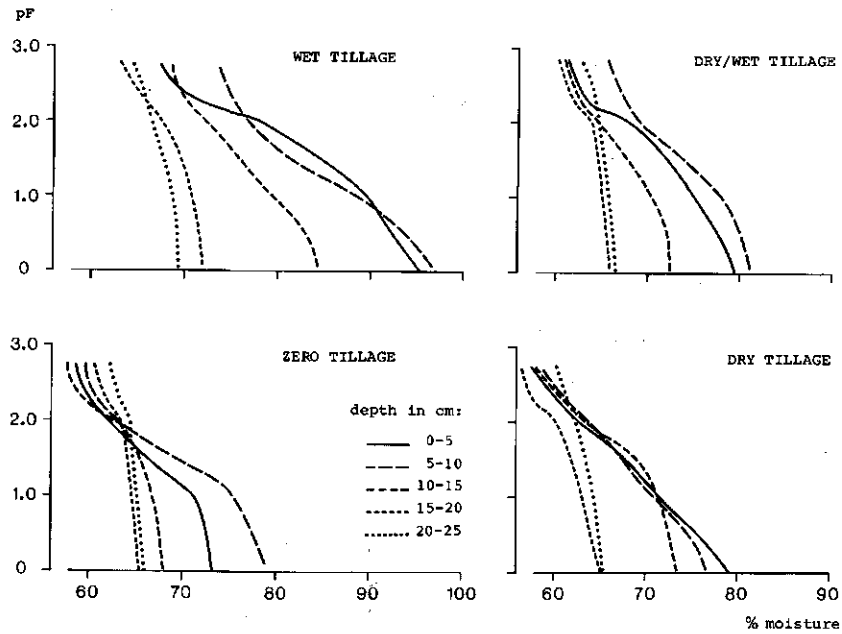


Figure 30. Dehydration curves of four tillage treatments at five soil depths.

lower moisture contents of this layer than of the 5-10 cm layer. It occurs with zero tillage with combine traffic at harvest in the absence of soil loosening by tillage, and with dry/wet tillage by wet seedbed treatment after dry plowing.

The water availability in the top 5 cm expressed as the amounts of released water on mass basis was larger between pF 2.7-4.2 than up to pF 2.7. At 20-25 cm, the difference was even larger (Table 32). Within the top 5 cm, availability decreased in the sequence wet-dry-dry/wet-zero.

.4 v.o. Variations in water release above pF 2.7 occurred in a more extremely treated soil in the laboratory (Fig.31), but were absent in the field samples (Figure 32). This soil differed slightly from that from the tillage trials, as seen in the dehydration curves. These curves indicate the theoretical range

Table 32. Available water as a percentage of dry soil weight at depth of 0-5 cm

	Wet tillage	Dry/wet tillage	Dry tillage	Zero tillage
Up to pF 2.7	28%	19%	21%	15%
pF 2.7-4.2	40%	34%	30%	30%

Averages for 20-25 cm layer with pF up to 2.7, 6%; with pF 2.7-4.2, 34%.

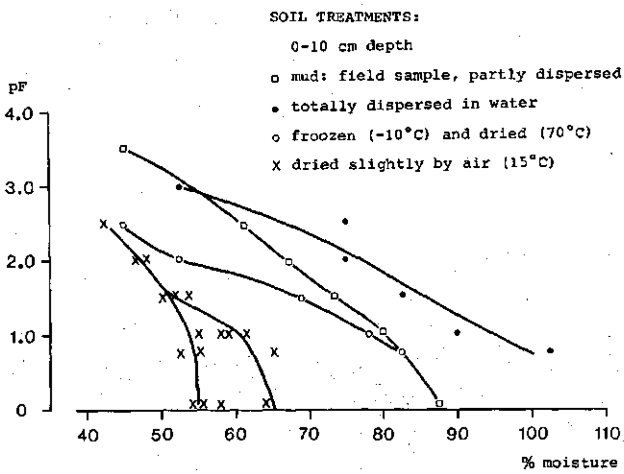


Figure 31. Course of dehydration under extreme laboratory conditions (after Koenigs & Scheltema, unpubl.).

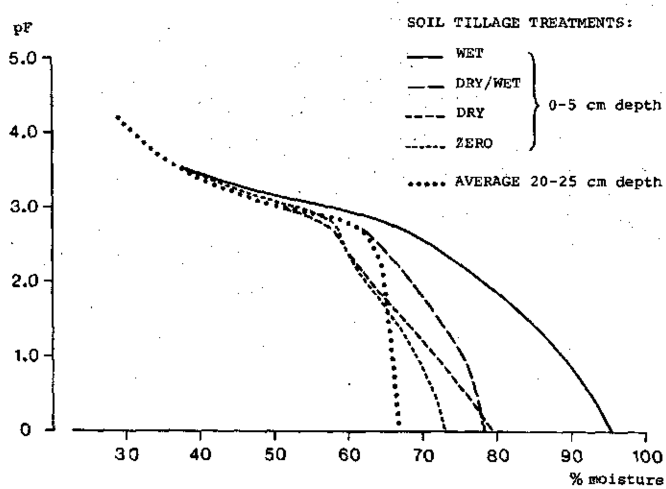


Figure 32. Course of dehydration under field conditions.

with its limits of totally dispersed soil and the slowly air-dried soil. In field conditions, the variations were much less and were restricted to the pF range below 2.7 (Figure 32).

Figure 33 shows the extracted soil moisture (v/v) in the range up to pF 2.7. The extracted soil moisture decreased with depth in all treatments. The decrease continued below the lower depth of the tilled layer. The compacted top 5 cm with zero tillage was the only exception. The available moisture (v/v)

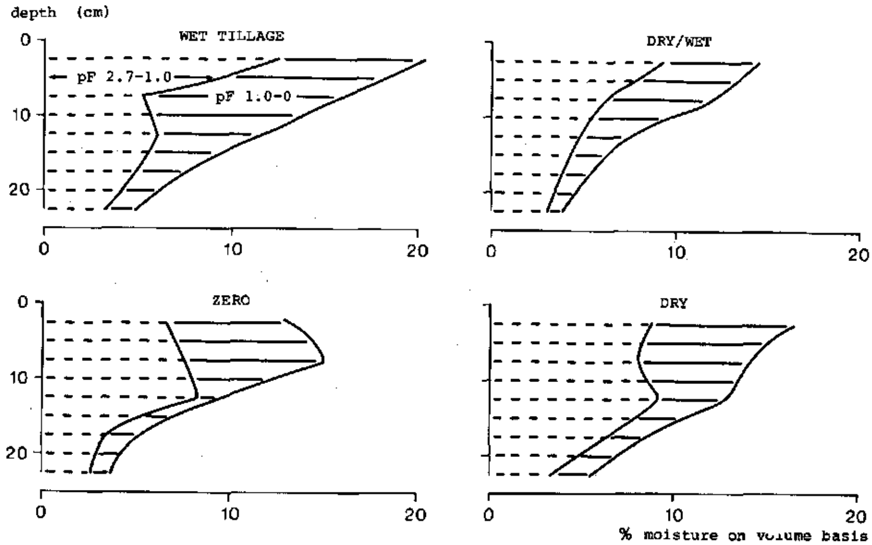


Figure 33. Available moisture up to pF 2.7 with four tillage treatments.

Table 33. Field pF values calculated from moisture values and dehydration curves.

	Wet tillage	Dry/wet tillage	Dry tillage	Zero tillage
0-10 cm below surface	2.7	0	0	1.0-1.5
10-20 cm below surface	2.7	0-1.0	0	1.5
20-30 cm below surface	2.7	0	0	0

below 5 cm is greater for dry and wet tillage than for zero and dry/wet tillage.

The values for extractable moisture have only limited use, as water will be transported from floodwater into the soil, if matric suction increases by extraction of soil water by plant roots. The water permeability of these heavy clay soils is given in 6.5. With the soil moisture data given in Figure 28 at the end of the rice growing season, and the dehydration curves, related pF values can be calculated. They are given in Table 33.

The calculated pF values at the end of the rice-growing season indicate a restricted reserve of water available to plant roots.

6.4 EXTRACTION OF SOIL MOISTURE

The preceding section discussed the differences between soil treatments in dehydration curves and available moisture. The data were from soil cores in which the water content was in equilibrium with applied suction levels. The

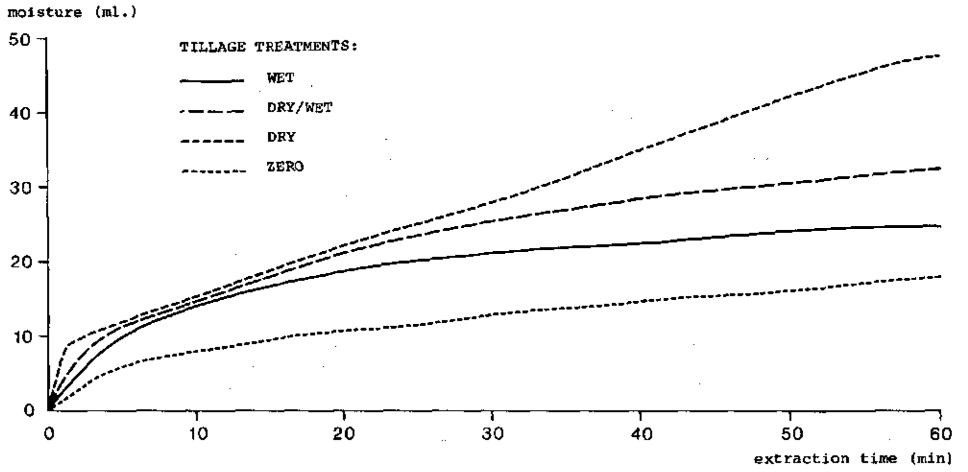


Figure 34. Effect of extraction time on the amount of moisture obtained.

factor 'time' was omitted from this approach. By extracting soil moisture at constant suction corresponding with pF 2.9, figures were obtained for release of soil moisture with time. A picture could be formed too of the changes in matric suction during extraction with potential probes.

To determine *rates of soil moisture release*, undisturbed soil samples were taken in the field at 5-10 cm and investigated as indicated in 3.1. Figure 34 gives the moisture extracted during a period of 60 minutes for soil treatments zero, dry/wet and wet. In the first 10 minutes, the amounts differ; afterwards they increased at the same rate, except for drv tillage whose rate was somewhat greater.

Table 34 compares the extracted amounts with the quantities of available

Table 34. Relation between total available moisture and extracted moisture up to pF 2.7 at 5-10 cm depth.

Tillage	Available moisture (%, v/v)	Extracted moisture at constant suction of pF 2.9, as percentage of available moisture up to pF 2.7		Extracted moisture, as a percentage of available moisture after 60 min
	up to pF 2.7	after 30 min	after 60 min	
wet	16	33	36	6
dry/wet	12	50	66	8
dry	14	50	84	12
zero	15	22	30	5

moisture calculated from pF core measurements (6.3). Obviously wet and zero tillage lag far behind dry and dry/wet tillage.

To measure *soil suction during extraction,* hydraulic potential probes (3.1) were filled with water (Figure 35). Three of them were placed 0.5 cm above the extraction surface, two 2 cm above, and two 4 cm above. The extraction force equivalent to about pF 2.9 could not be reached. Above pF 2.9 (equivalent to 0.75 bar), gas formation will prevent higher capillary suctions in the water-filled tubes. Neither in the field (6.6) nor in soil-extraction pots were values above pF 2.1 (above 130 cm water height) measured with these potential probes.

Moisture contents of soil samples after extraction showed suction values corresponding with pF 2.9, proving the existence of higher matric suctions in the soil than indicated by the potential probes. Positive tensions are due to the slight pressure needed to place the probes in the soil.

Conclusions can be formulated as follows:

Wet tillage. The probes reach their suction tension almost immediately and remain stable during the whole procedure. Sometimes a sudden drop to a lower stable level may indicate a blockage in the pore system, or a break in the connection between the probe's opening and its contents by collapse of pores. All deeper probes react and indicate high suction tensions.

Dry/wet tillage. Only a few probes react. The suction level varies within short periods.

Dry tillage. Fluctuations in matric suction predominate, because water flow is disturbed by enclosure of air in large pores, which have to be sucked out before the water in smaller pores beyond the air lock can pass.

Zero tillage. The suction pressure is transmitted throughout the soil sample almost from the start through the well interconnected pore system. The pattern resembles that of wet tillage, but sudden drops are absent. All probes approach one average value. The mechanical structure seems to be sufficiently stable to prevent collapse of the pores.

The low percentage of total soil moisture recovered with wet or zero tillage corresponds with the stable suction values in the extracted soil sample. There, water has to pass through small pores with capillary tensions only slightly below the extraction force, whereas, with dry tillage, large pores are available for water transport.

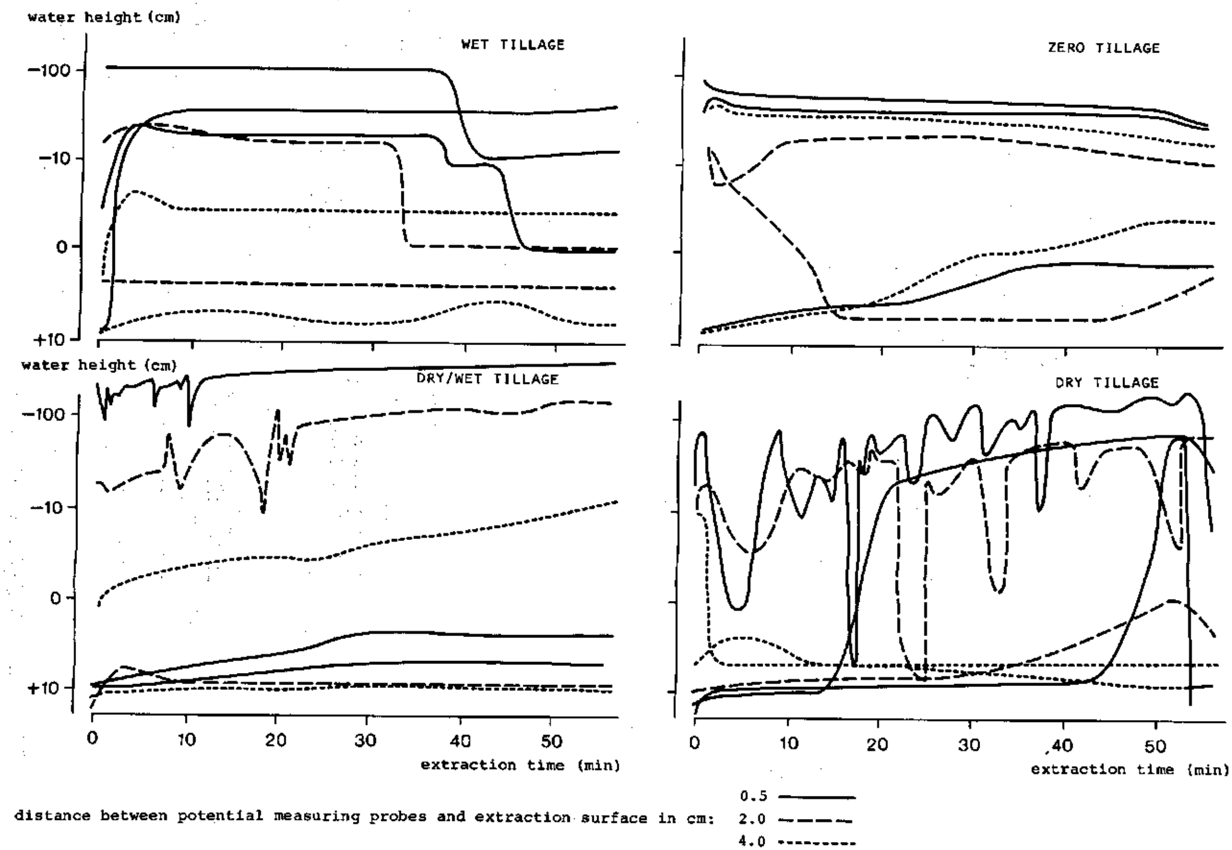


Figure 35. Moisture potential in soil during moisture extraction as measured with hydraulic potential probes.

6.5 PERMEABILITY TO WATER

Permeability measurements were carried out on ricefields a month after flooding to promote saturation of the profile (3.1). It took a month for the soil to equilibrate with the water level in the tube. Permeability, K , is defined as the column of water passing through a column of saturated soil 1 metre high at a hydraulic pressure of 1 m H_2O divided by time. Saturation was not always achieved in masurements; matric suctions vary between 10 and 60 cm (6.6.2).

The calculated values refer to the highest possible water movements in the soil, as desaturation will increase during the growing season with wet tillage.

Table 35 gives the ranges of permeability. Two zones could be distinguished: one below the tilled layer at 15-45 cm depth, one other at 45-100 cm. The values varied much, but in the 15-45 cm layer the ranges differed distinctly: puddling decreased permeability as high values were absent. Dry plowing resulted in larger variation. With wet tillage, permeability was almost too low to be recorded, whereas for dry tillage, values, though low, were easily measurable. Dry/wet tillage was intermediate. Between 45 and 100 cm, differences between the tillage treatments were absent and the values were far higher than those in the 15-40 cm zone.

For the 0-15 cm layer, figures are missing. In the laboratory procedure to estimate K, the overpressure of 10-50 cm H_2O was insufficient to release water from the wet tillage sample, and when a suction equivalent to pF 2.9 was applied, the pores collapsed (6.4).

In swamp soils and recent reclaimed rice soils, permeability of the 20-50 cm layer was still usually 100-400 cm/day and equalled those in the 50-150 cm zone. The high permeability was based mainly on the presence of many large interconnected open channels of former roots. After reclamation, these channels are partly filled with soil material brought into suspension by puddling, and are partly deformed and shut by stress from swelling after wetting of the soil.

Table 35. Ranges of water permeability

Tillage	Wet	Dry/wet	Dry
15- 45 cm below surface	0- 3 mm/day	4- 15 mm/day	8- 70 mm/day
45-100 cm below surface	100-2000 mm/day	100-2000 mm/day	100-2000 mm/day

Data represent averages of 4 or more measurements

6.6 SOIL MOISTURE POTENTIALS

6.6.1 *Calculated data*

As shown in the previous sections of this chapter, the four tillage treatments result in different initial moisture contents in soil and in different changes during the rice-growing season. Consequently the dehydration curves also differ, though they all drop steeply below 15 cm depth in the pF range up to 2.7. A small decrease in soil moisture content below saturation is sufficient to produce matric suctions in the soil during the rice-growing season.

To gain some information about this matric suction, the procedure described in Section 3.1 was used for inserting a piezometer tube. The water level in the tube dropped during the growing season and ultimately became empty. In a field after wet tillage, the emptying of the tube indicated the lowering of the hydraulic potential during the rice-growing season.

Theoretically the total moisture potential equals the sum of the atmospheric (ψ_p, assumed to be constant), the gravity (ψ_g, not interfering with soil moisture withdrawal by plant roots), the matric (ψ_m) and the osmotic potential (ψ_o);

$$\Psi = (\Psi_p) + \Psi_g + \Psi_m + \Psi_o$$

The matric and osmotic potentials govern the water availability for plant roots, the first also the water movement in the soil. The potentials can be expressed as energy divided by weight (expressed, for instance, in erg/g) so that:

$$\psi = g\Delta h + VP - V\Pi$$

in which Δh is the altitude in the profile, g is acceleration due to gravity, V is the specific volume of water (so printed, to distinguish it from v, velocity), P_V the matric suction, and Π the osmotic pressure. The hydraulic potential (P^*) governing the water movement in the soil expressed per volume of soil is:

$$P^* = P_V + \rho g\Delta hh \qquad (1)$$

in which ρ is mass density.
The values of P^* can be calculated from the Transport Equation (Eq.2) as long as the continuity rule (Eq. 3) is satisfied:

$$v = K_h \, dP^*/dh \tag{2}$$

$$d\Theta/dt = -(dv/dh + S) \tag{3}$$

in which Θ is volume fraction of moisture in soil, t is time, v is velocity, S is a constant for the source. Equation 2 states that the velocity changes in proportion to the driving force, with K as the transport coefficient of the medium. Equation 3 indicates, during movement, the increase in the liquid per volume of medium and per unit time. This equals the difference in flux through the boundary planes perpendicular to the direction of movement, while a constant source regulates the movement.

Based on these general equations, ir. P. Koorevaar and dr. F.F.R. Koenigs of the Laboratory of Soils and Fertilizers supplied an equation with the aid of which the matric potential in relation to depth can be calculated. The driving force of the downward water movement is the withdrawal of soil moisture by the plant roots. The removed water is replaced by flood water. The following assumptions are made:

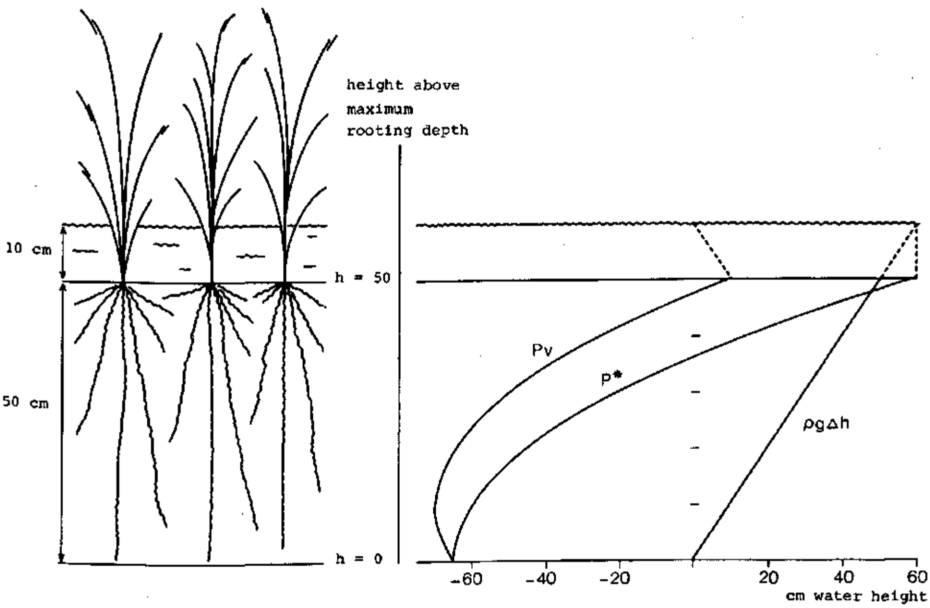


Figure 36. Model of transport of floodwater to the rooting zone (replenishment of transpired water), and calculated moisture potential curves

(a) the transpiration is continuous, (b) the permeability and moisture content do not change with depth or time, (c) the root distribution and water uptake is uniform from the surface to maximum rooting depth and (d) no water transport from below the maximum rooting depth occurs. The volume fraction of moisture (θ) is constant at a given depth, so that

$$d\theta/dt = 0$$

By substituting in Equation 3

$$- dv/dh = + S$$

in which h is restrictively defined as the height above the maximum rooting depth.
After integration for h:

$$v = -Sh + C \qquad (4)$$

where C is a constant

At h = 0, v is also zero, hence $C = 0$.

Substitution of Equation 6 in the transport equation (Eq.2) gives

$$-S.h = K_h \ (dP^*/dh)$$

where K_h is the hydraulic transport coefficient of the medium.
and integration for h results in

$$P^* = (Sh^2/2K_h) + C \qquad (5)$$

Pressures have been expressed in cm water or mbar with the maximum rooting depth as reference level (h = 0). Thus the gravity potential at the soil surface is h_{max} (maximum). The matric suction P_v at the soil surface equals the depth of flooding d. Consequently the hydraulic potential at the soil surface is

$$P^* = h_{max} + d$$

By inserting the known values of P^* and h at the surface, the value of C is found, if values for S and K_h representative for the situation are inserted.

The conditions in the Wageningen Polder can now be inserted. The lower boundary of the root system is at 50 cm (Section 8.3), so that there the downward movement of water is zero. The transpiration rate is 0.5 cm/day, the water permeability K_h = 0.1 cm/day, the depth of flooding is 10 cm.

The assumption of uniformity of soil and root system is a simplification. The permeability is chosen in accordance with field measurements in the 15-45 cm layer after wet tillage treatments (Section 6.5). The results are

$$S = - 0.5/50 \text{ day}^{-1} = - 0.01 \text{ day}^{-1}$$

and the hydraulic potential at the soil surface is

$$P^{*} = h_{max} + d = (50 + 10) \text{ cm}$$
$$= 60 \text{ cm}$$

Equation 3 may now be written as

$$0 = - (dv/dh) - S$$
$$0 = - (dv/dh) - 0.01$$

and, after integration for h,

$$v = - 0.01\ h + C$$

If h and v are zero, C is also zero.

Substitution in the transport equation (2) gives

$$-0.01\ h = - K_h\ dP^{*}/dh$$

With a water permeability of 0.1 cm/day and after integration for h (Eq. 5), this gives

$$P^{*} = (0.001\ h^2/2 \times 0.1) + C$$

$$P^{*} = (h^2/20) + C$$

At the soil surface, h is 50 cm and P^{*} is 60 cm water, which makes C -65. Subtraction of the height from the P^{*} values gives those of the calculated matric suction. For a permeability of water of 0.1 cm/day, they are included

Table 36. Calculated matric (P_v) and hydraulic potentials (P^*) and water transport rates for a uniform soil with a rooting depth of 50 cm and a transpiration of 0.5 cm/day at different values of water permeability

		cm below the surface					
	P_v	0	10	20	30	40	50
	cm water height						
Water permeability (cm/day)	1	10	15.5	22	19.5	38	47.5
	0.1	10	- 25	- 50	- 65	- 70	- 65
	0.01	10	-430	-770	-1010	-1150	-1190
	P^*						
	cm water height						
Water permeability (cm/day)	1	60	55.5	52.0	49.5	48.0	47.5
	0.1	60	15	- 20	- 45	- 60	- 65
	0.01	60	-390	-740	- 990	-1140	-1190
	water velocity (cm/day)	0.5	0.4	0.3	0.2	0.1	0.0

in Figure 36. For comparison, the moisture potentials of soil calculated from assumed permeabilities of 1, 0.1 and 0.01 cm, respectively, are given in Table 36.

6.6.2 *Field measurement of matric and hydraulic potentials*

Matric and hydraulic potentials were measured with three types of instruments: piezometers, tensiometers and potential probes. In this order they represent soil volumes decreasing in size: the smaller the volumes, the closer the the simulation of actual plant root environment (3.1).

6.6.2.1 Piezometer tube

Orientational piezometer measurements (see 6.6.1) showed that the levels in the piezometer do not coincide with those of the inundation water. To study this phenomenon, four series of tubes, 10 cm diameter, were put into the soil to measure the effect of tillage, reclamation and distance to the nearest ditch.

The *tillage effect* can be judged from Figure 37, referring to the growing season of the rice crop. The water levels were plotted against soil surface as reference level. The variations in floodwater level were due to rainfall and drainage periods.

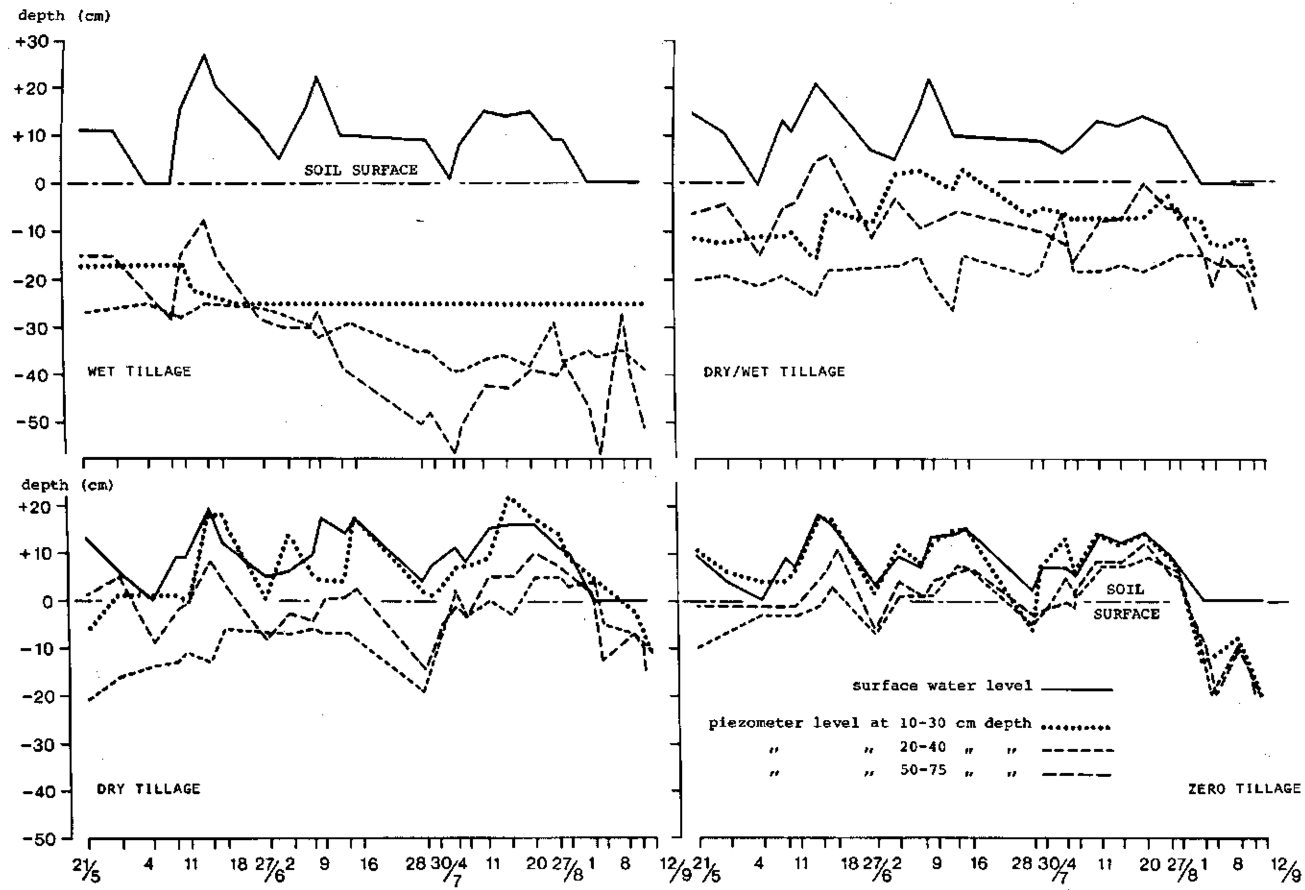


Figure 37. Effect of different tillage treatments on piezometer levels in land reclaimed 20 years previously. The 4-days surface drainage periods occured around split applications of urea on 4 June, 2 July and 4 August. The rice was sown on 14 May and harvested on 21 September.

With zero tillage, the piezometer level coincided with the surface water; with wet tillage they did not; with dry and dry/wet tillage the pattern was intermediate: dry tillage tended to resemble zero treatment, dry/wet tillage the wet treatment.

Three phenomena must be discussed here:

(1) differences in piezometer levels between soil horizons and from the surface water level

(2) a reaction of piezometer levels to a change in floodwater level

(3) a reaction of piezometer levels to a period of high transpiration of the rice crop

(1) Differences in the piezometer levels were already observed at the start of the measurements between depths and between tillage treatments. They were due partly to differences in water saturation (caused by the variation in length of the inundation period see 6.1) and in puddling intensity, partly to differences in the rate with which the tube holes filled with water.

Differences in piezometer heads between soil horizons were present in all treatments. With wet tillage, they distinctly increased during the growing season. In the dry and zero treatment, they decreased. The position of dry/wet tillage was intermediate. The soil moisture data in 4.2.1 agree with this pattern.

In the 10-30 cm zone, with zero and dry tillage, the piezometer level coincided with those of the surface water. With dry/wet tillage, the distance between the two first decreased (till the end of June), but afterwards increased. Wet tillage caused complete drainage of the tubes after mid June.

In the 20-40 cm zone, the differences from the surface water level increased in the order zero (5 cm), dry (5 cm), dry/wet (35 cm), wet (45 cm). During the growing season, with zero and dry tillage, the levels tended to equilibrate. After the dry/wet tillage, the difference was almost constant but distinct. With wet tillage, it continued to increase.

In the 50-75 cm zone, the piezometer level with dry and zero tillage were below the surface-water level, at the same level as for the 20-40 cm zone. With dry/wet tillage, they were distinctly higher than in the 20-40 cm zone. With wet tillage, levels decreased with depth.

Differences in piezometer levels with the floodwater were observed as matric suction indications. They were low and corresponded with at most 30-50 cm water. Between 10 and 30 cm depth, with wet tillage the piezometer tubes were completely empty; in other words, matric suction occurred.

(2) The reaction to a change in floodwater level was not the same for all soil

layers. In the 50-75 cm zone, it was distinct or (with wet tillage) it was masked by the general tendency of piezometer levels to fall. With wet and dry/wet tillage, no reaction occurred in the 20-40 cm zone; with dry tillage, it was weak, and only with zero tillage was it distinct.

In the 10-30 cm zone, despite different levels in the piezometer, the reaction to changes in surface water was absent or only hardly perceptible (that of wet tillage could not be measured because of complete drainage of the tube).

(3) The balance in the piezometer tubes is based on the supply of water from the soil and the uptake by plant roots. Early in the season, supply exceeds uptake, so that the soil becomes more saturated and piezometer levels tend to rise. Uptake by plants depends on transpiration per unit area, which depends on the cover of the soil by the crop and on the potential evapotranspiration. The rice completely covers the ground in July; during that month, transpiration was higher, and the result was a decrease in the piezometer levels in the 50-75 cm zone of all tillage treatments. This decrease varied with tillage treatment, from zero (2 cm), dry and dry/wet (5 cm) to wet (20 cm). Only with dry and zero tillage was the decrease reversed later in the season, and even changed into an increase near the end of it.

With dry and zero tillage, no reaction to the period of higher transpiration was observed in the 20-40 cm zone. The reaction was slight with dry/wet, and distinct with wet tillage.

In the 10-30 cm zone all tillage treatments react, though for wet tillage this could not be recorded.

The *reclamation effect* resulted in an entirely different pattern in the piezometer levels of recently reclaimed swamp soils (Figure 38): the reactions to the various levels did not agree with those of the soils reclaimed 20 years before. All piezometer levels of different soil layers of the tillage treatments nearly coincided with the surface water level.

Figure 39 shows that in a *fallow* field, covered with some stubble and weed growth from the previous rice crop, 20 years after reclamation an apparent groundwater table occurred in the poorly permeable 20-50 cm zone, above the groundwater level in the permeable subsoil.

The effect of the *distance to the ditch* on the piezometer levels is shown in Figure 40. The preceding discussion referred to tubes placed 20-25 m from the drainage ditches. For a different season, the piezometer levels were plotted as differences from the level of the surface water or from the soil surface in drainage periods. At 4 m from the ditch, the reaction to drainage

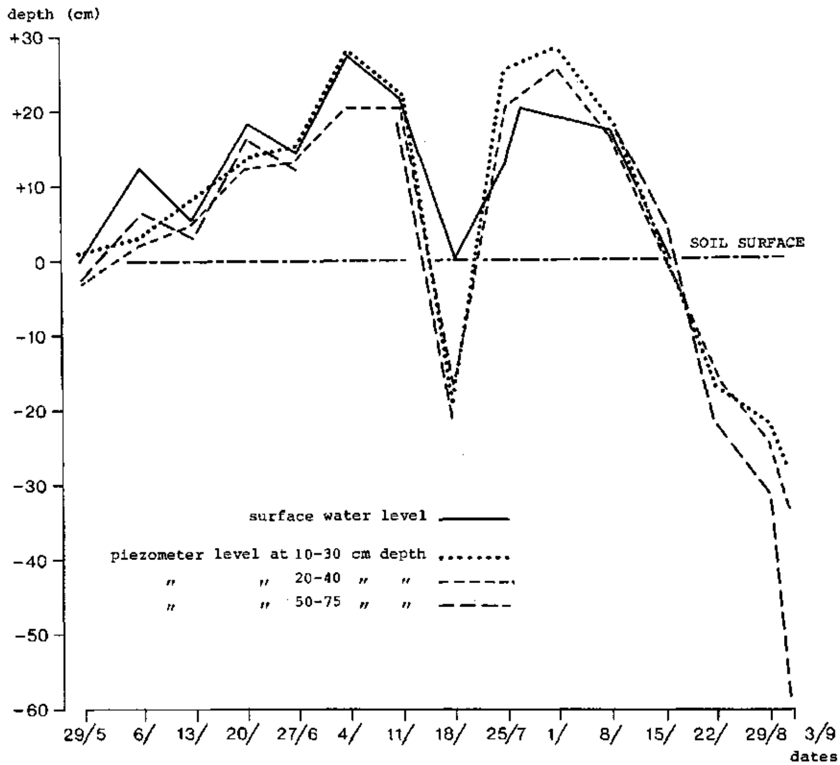


Figure 38. Effect of recent reclamation on piezometer levels with wet tillage.

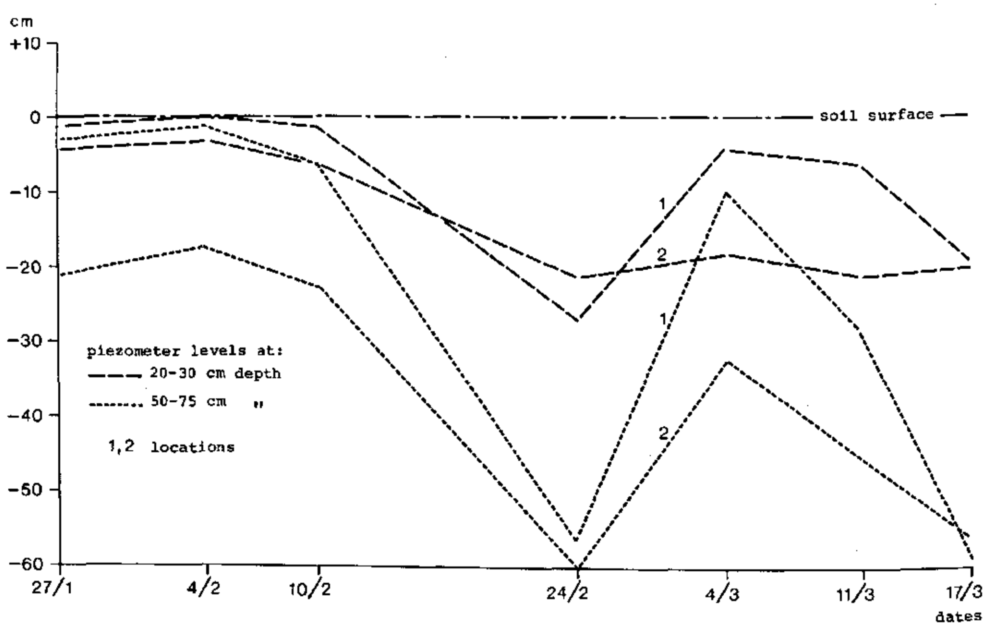


Figure 39. Effect of a fallow period on piezometer levels in land reclaimed 20 years previously.

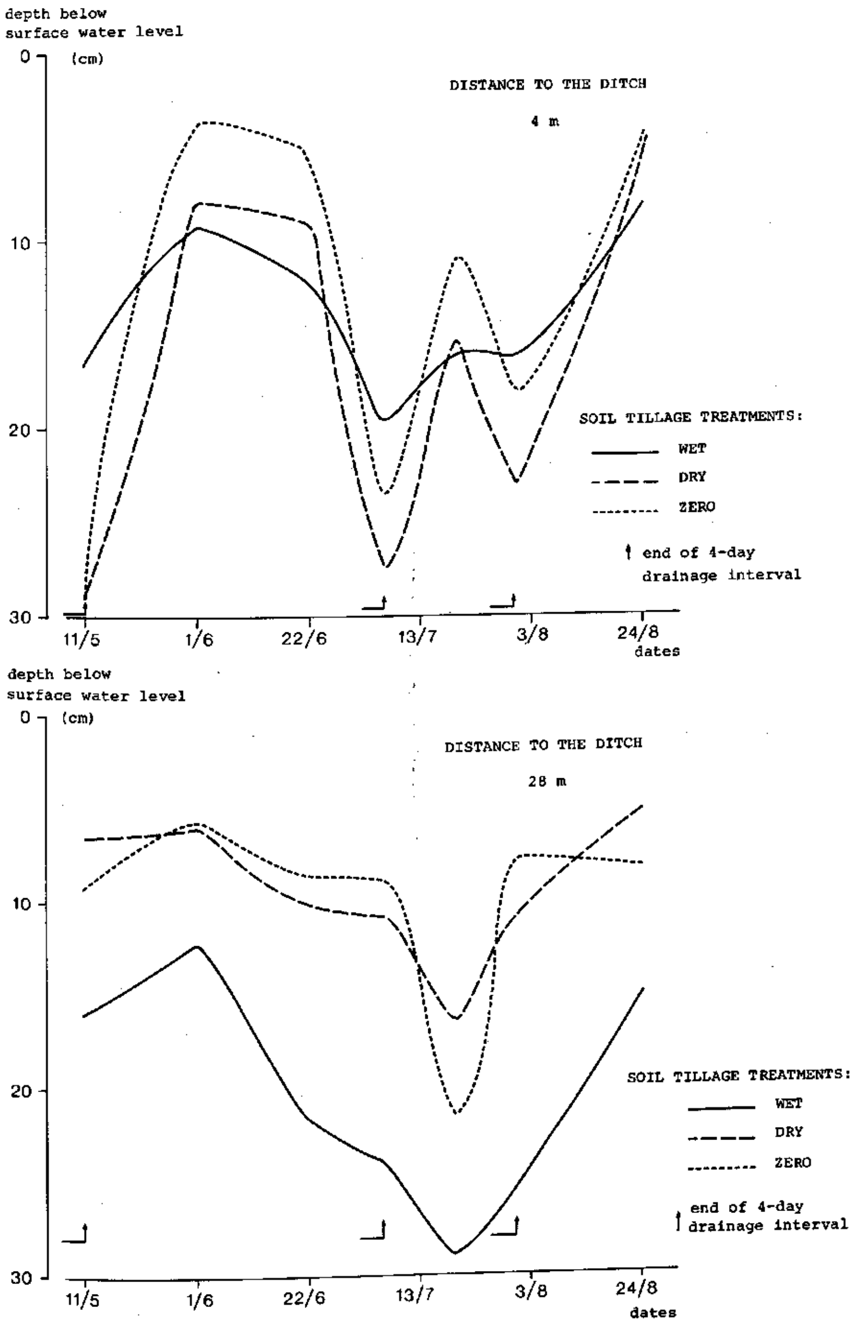


Figure 40.Effect of distance to ditch on piezometer levels in land reclaimed 20 years previously.

of the ditch was quicker for dry and zero tillage and slower for wet tillage. Dry/wet tillage was not incorporated in this tillage experiment. At 28 m in none of the tillage treatments did the drainage effect the piezometer levels.

Around 20 July, a period of high transpiration did effect the levels in all treatments. The rate at which this decrease was restored in a period of lesser transpiration thereafter increased in the sequence zero, dry, wet tillage.

From the reaction of the piezometer levels at both distances from the ditch, it was shown that the differences in piezometer level from the surface water level increased with distance with wet tillage, but not with dry and zero tillage. In the period between the second and third drainage interval, all treatments showed an increase in piezometer level at 4 m and a decrease at 28 m. This period coincided with high potential evapotranspiration.

The piezometer data will be discussed with a model of water movement through the soil as indicated by arrows in Figure 41. Three soil horizons (0-15, 15-50 and 50-150 cm) and three directions of water movement (lateral, upward and downward) were distinguished.

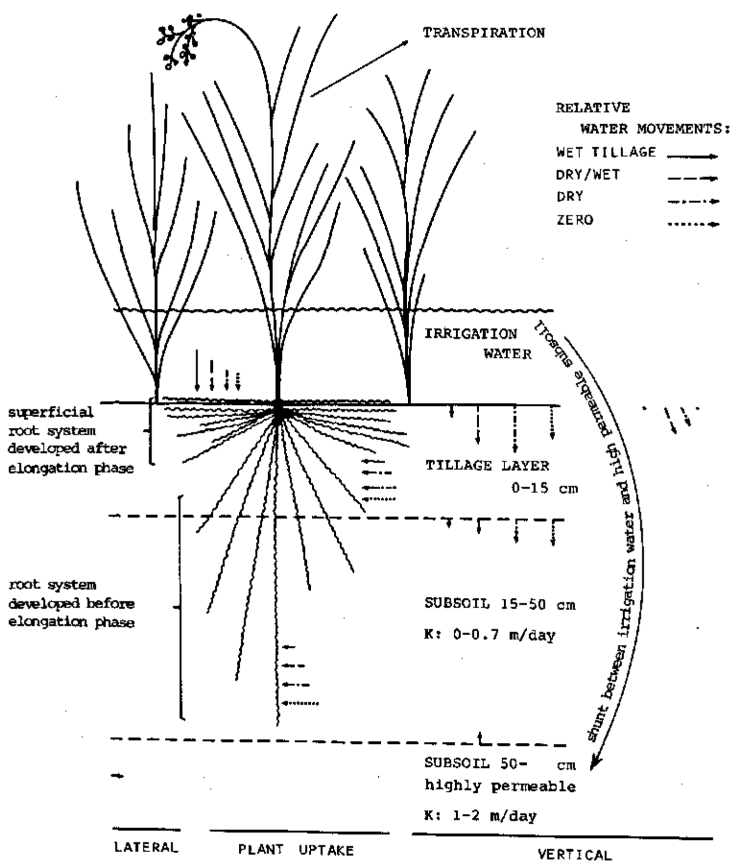


Figure 41. Model of water transport through soil and plant.

At the beginning of the rice-growing season, the roots were directed downwards with a maximum rooting depth of 50 cm. All water transpired by the plant was extracted from the soil. In the second part of the growing season, after the stems had elongated, an additional root mat developed (8.3), which partly took over the function of the deep roots in the transpiration process by taking up floodwater. This explains why the piezometer level stopped falling, later on in the growing season at wet tillage (Figure 37 after 4 August; Figure 40 after 20 July). Ultimately the water level in the piezometer may rise.

In the land reclaimed 20 years before, the low water levels in piezometer tubes when rice plants were present were due to low permeability of the upper 50 cm (6.5.2). In the recently reclaimed swamp, piezometer measurements did not record it, as both the puddled topsoil (due to presence of pegasse see 5.6) and the 20-50 layer (6.5) were more permeable. When fallow, an apparent groundwater layer occurs on the impermeable 20-50 cm layer.

The rice plants extract the water from the soil in different ways. In all tillage treatments, water moves through the soil. For dry and zero treatment, its direction was only downward. With wet tillage, the horizontal movement in the soil had only a low gradient (0.004) and took place from the ditch through the permeable layer below 50 cm (see Figure 41). Only small amounts of water were involved, as shown by the piezometer values in the 50-70 layer (Figure 37).

Water movement upwards from the layer below 50 cm to the 20-40 cm layer occurred with dry/wet tillage; there a gradient compensating for the gravity component was present (Figure 37).

With dry and zero treatment, water moving downwards through the tilled layer follows cracks and large pores. The differences in piezometer levels between dry and zero tillage in the 20-40 cm zone indicated a certain blockage of transport after dry tillage in the upper 20 cm. As the tilled layer consists of clods, this blockage presumably occurred below the tilled layer, indicating a plowsole, though its presence was not noted in the micromorphological soil description (Chapter 5).

After wet tillage, the movement of water downwards was hampered by the puddled layer, in the upper part of which a sedimented layer blocked transport, since it lacked larger pores. In the puddled layer and below it, water transport may be blocked by inclusions of gas, which would explain the absence of a reaction of piezometer levels in the 20-40 cm layer to changes in the level of floodwater. This could also be due to collapse of pores with increased matric suction, as noticed during extraction of soil moisture (6.4).

With dry/wet tillage, the phenomena during the downward transport with wet tillage occurred also, though less pronounced. There the sedimented layer was less distinct and more often interrupted, but still may have led to a lack of reaction to floodwater between 20 and 40 cm in the piezometer. The assumed effect of a plowsole with dry tillage must be present here, too.

Peculiar was the higher piezometer level of the permeable layer below 50 cm (down to 100-150 cm). Presumably it was caused by direct ('shunt') connections between the floodwater and this layer, which may be present either laterally through the ditch wall or vertically along larger pores from former roots. Only with wet tillage were these connections severely blocked, causing the lowest piezometer values in the profile to occur in the 50-70 cm layer. This blocking is, however, not complete, as changes in floodwater level are followed by the piezometer level in this zone after wet tillage. Piezometer levels in the 50-70 cm layer reacted to changes in floodwater level in all tillage treatments. In the absence of a reaction in the 20-40 cm layer, it indicates the existence of shunt connections.

Figure 26 shows the water movement in the soil in different periods; to obtain a clear model, the influence of rainfall was ignored. In the pre-tillage period, the field was surface-drained. The evaporation of the soil surface depended on many factors (4.2). In practice, the moister fields will be puddled, the drier will be plowed.

During the tillage period, water enters the soil from above. With wet tillage, water enters the soil during flooding, before puddling, through small cracks and any pores. After puddling, water transport to below the puddled layer is restricted. With dry tillage, water enters the soil late, but is favoured by plowing, as the tilled layer consists of clods, and cracks are still present through the tilled layer. In all treatments, some water will enter laterally from the ditch.

At the start of the rice-growing season, some water will move downwards to compensate for extraction by the rice roots. This transport is severely hampered in the puddled layer.

Under the closed rice crop, a situation occurs, as discussed in the text to Figure 41.

6.6.2.2 Tensiometers and hydraulic potential probes

The piezometers used consisted of wide tubes. This had the drawback that water levels reacted only slightly: a change of 1 cm water height corresponded to about 80 cm^3 water transport. If the soil is not homogeneous with respect to its moisture potential, the piezometer indicates this by its lowest level. Even so, remarkable differences in piezometer levels between tillage treatments were found.

To obtain more information about water availability for rice roots, tensiometers and potential probes were used (3.1). These instruments have a contact area with the soil of 35 and 0.03 cm^2, respectively, whereas the piezometer tubes have a contact area of 300 cm^2 with the soil. Evapotranspiration during these experiments was lower than in the season in which the piezometer values of Figure 37 were obtained. Piezometer tubes placed together with these instruments showed a less distinct reaction than before. This season effect can be caused also by vertical water transport through shunt connections (cracks or holes) due to intensive drying before tillage.

Tensiometers were placed at 10 and 20 cm depth. The data represent individual values.

The differences between the tillage treatments were almost absent at 10 cm depth (Figure 42). After wet and zero tillage, values tended to be higher. Overpressure does occur at this depth.

At 20 cm depth, the tensiometer values differed between tillage treatments. With wet treatment, matric-suction values of 20 cm water height were obtained. With zero and dry tillage, values were about 10 cm water height, but showed some peak values equal to the wet tillage level.

Hydraulic potential probes were placed at 5, 10, 15, 20, 40 and 60 cm depth.

The matric suction values indicated by the potential probes ranged from +80 to -50 cm water height. The variability was large; significant differences between the soil tillage objects were absent. They could be considered as point measurements. To characterize tillage treatments, a tremendous number would be needed, because of their high variation from point to point.

During the rice-growing season, three patterns could be distinguished (Figure 43).

1. little variation at an almost constant level
2. continued increase or decrease at a slow rate
3. great changes within a short time

(1) The soil could be smeared around the opening, resulting in a lack of contact. Only overpressures due to installation could occur in this way.

(2) A continued slow decrease in matric suction can represent water replacement. It also may represent a build-up of gas pressure. A continued slow increase can represent water extraction by roots or gas dissolving or escaping.

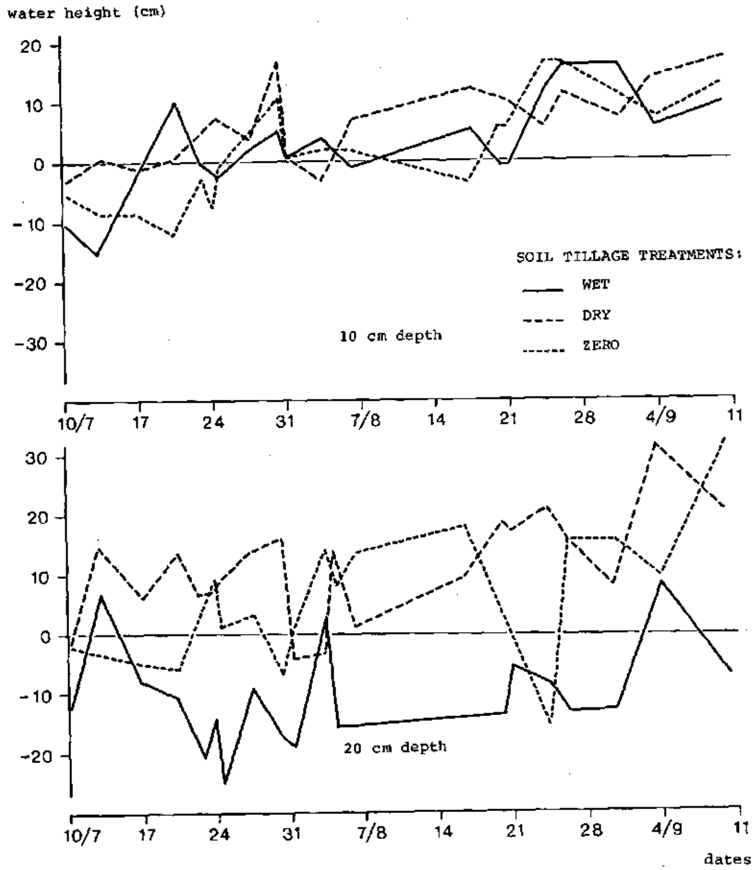


Figure 42. Matric suction measured with tensiometers for different tillage treatments.

(3) In general suction increased, except in the upper layer (5 cm) of the dry and zero treatments.
Some large fluctuations occurred at short intervals. Sometimes this fluctuation to a much lower suction coincided with reflooding after a drainage period of 4 days. After some days, this fluctuation was restored. Air inclusion and gas formation due to the drying effect of the drainage period could cause this effect. Sometimes the fluctuation was not associated with reflooding and was not restored afterwards. The fluctuation may be positive or negative. Gas formation or local extraction of water by roots may be the reason. This occurred frequently with the wet and zero tillage at all depths. With dry tillage, it was almost absent below 15 cm.

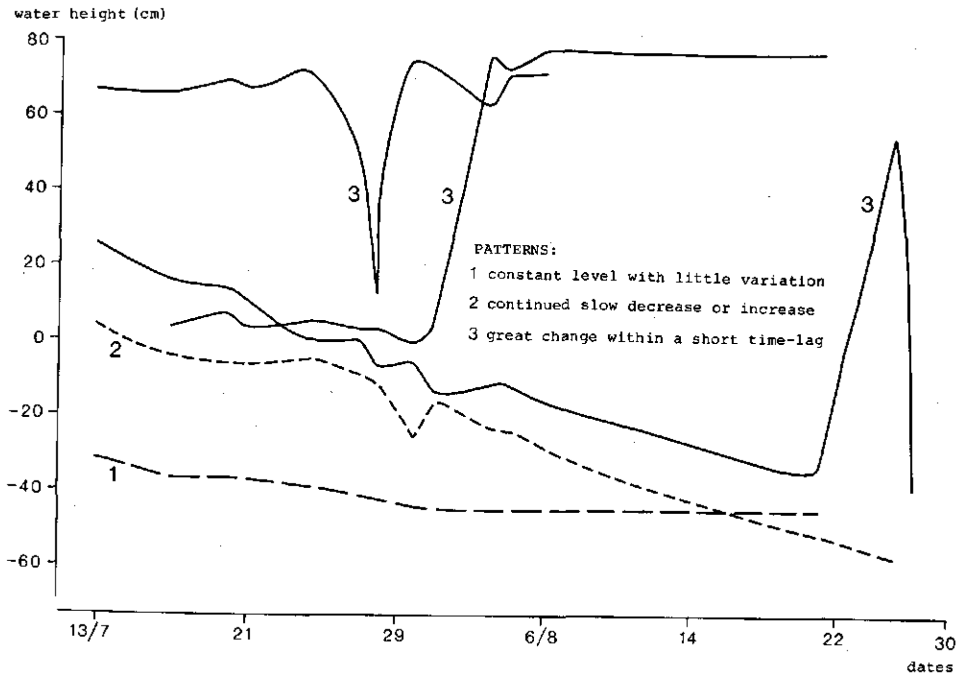


Figure 43. Changes in patterns of matric suction, measured with hydraulic potential probes.

The use of potential probes has the disadvantage of (1) large temperature effects and (2) practical limitation of measurement levels above 90 cm water height.

(1) The air bubble volume is strongly influenced by temperature. The change in the air volume mostly influences the water/air surface in the open leg of the water manometer. An increase in temperature increases the air volume between the two water volumes. As the resistance in the open leg is less, the increase in air volume causes first a decrease in the water level at the open end of the manometer. As water is pressed into the soil by the air pressure, the water level at that end of the manometer decreases too. Readings were taken early in the morning to minimize differences in temperature and to allow equilibration during the night. Measurements at noon and in the afternoon were recorded, too. Sometimes during day time, the decrease in the soil contact leg of the manometer exceeded those in the open water leg, indicating an increased suction of the soil compensating the temperature effect in the air volume. However, absolute

increase in suction could not be distinguished.

(2) In the laboratory, the practical limit of potential probes was 130 cm water height (6.4). In the field, maximum recorded values of 90 cm water height overpressure are the practical limit.

The data of the tensiometer and hydraulic potential probe will be discussed and compared with the piezometer measurements. The tensiometer measurements were restricted to the top 20 cm. In the 10-30 cm zone with wet tillage, the piezometer tube was drained and indicate a matric suction. In the tensiometer, maximum readings of 20 cm water height were recorded. The potential probes showed values ranging from +80 to -50 cm water height. The potential probe apparently measured a wider range of matric suctions than piezometers and tensiometers.

In the 20-40 cm zone, piezometer tubes indicated a relative suction, with a water pressure falling towards zero, as the presence of water excludes the occurrence of a matric suction. Hydraulic potential probes indicated that matric suctions up to 50 cm water height occurred locally.

Overpressures in the soil were not measured with the piezometer tube and the tensiometer; they were indicated by hydraulic potential probes and varied widely in the soil. Overpressures indicate gas inclusions which may block pores for water transport.

The calculated matric suctions based on assumptions and the measured ones will be discussed next. The data (Figure 36) were calculated for the situation with wet tillage. At 10 cm depth, the values measured with the tensiometer indicated a pressure of about zero, at 20 cm depth of about minus 20 cm water height. These values were in accordance with the calculated ones. At 30 cm depth, a drained piezometer tube indicates that a matric suction still occurred, but its magnitude is unknown. At greater depths, piezometer tubes show a water pressure of zero or more and deviate strongly from the calculated data, which show increased matric suction with depth.

The deviation between calculated and measured data on water pressure is assumed to be caused by the postulated uniform rooting depth and -activity down to 50 cm. From the measured data, it is concluded that water extraction from the soil is limited to the top 20-30 cm mostly in the early part of the growing season, while after stem elongation and formation of the rootmat (8.3) water extraction is concentrated in the top centimetres.

6.7 OSMOTIC POTENTIAL MEASUREMENTS

Apart from matric suction the plant root has to deal with the osmotic potential, which acts additionally. By concentrating on small portions of the soil mass, the variation and maximum values of matric suction increased. Moisture could not be extracted from small portions of soil because of technical difficulties. A suction caused collapse of pores around the opening of the potential tube in the soil, so that moisture could not be extracted. Data on osmotic potentials refer only to soil volumes of 300 cm^3, with an extraction surface of about 60 cm^2 (3.1).

Electrical conductivity provided data on osmotic potentials. The range of values by depth during the rice-growing season is given in Table 37. The data represent 20 or more single measurements. No regular trend in these data during the rice-growing season was observed. Hence only their summarized range over the whole season is presented.

An increase in conductivity with depth was observed. At the lower boundary of the tilled layer, a sharp increase was noted. The higher salt concentrations at greater depths were due to the marine origin of these sediments. Diffusion of salts from the soil to the floodwater with low salt concentration and vice versa is most restricted with wet tillage. This restriction was due to the presence of the sedimented layer, which caused a high minimum conductivity with wet tillage. Diffusion was most facilitated with dry tillage, causing generally low conductivity.

To evaluate these conductivity values, they are compared with osmotic pressure and pF values in Table 38.

Table 37. Range of conductivity in mmho/cm at 25 °C during the rice-growing season, calculated from at least 20 measurements

Depth	Tillage				General values
	wet	dry/wet	dry	zero	
0- 5 cm	0.9-1.5	0.6-1.2	0.5-0.9	0.9-1.4	0.5-1.5
5-10 cm	1.6-2.0	1.0-1.7	0.9-1.9	1.2-2.1	0.9-2.1
10-15 cm	2.5-4.8	2.0-4.5	1.5-3.5	1.8-4.5	1.5-4.5
15-20 cm	2.7-5.5	1.7-5.0	2.0-4.5	2.0-6.0	1.7-6.0

Table 38. Relation between osmotic pressure, conductivity and pF values

conductivity at 25 °C (mmho/cm)	0.7	2.2	5.0
osmotic pressure (atm.)	0.2	0.7	1.8
pF values	2.3	2.8	3.2

The salt concentration of the soil moisture as indicated by conductivity is high. The literature shows also that yield of rice will decrease with conductivities above 4.0 mmho/cm at 25 °C (2.1). The reported trials were mostly on soils low in clay in which matric suction was not measured.

At 10-15 cm depth at Wageningen Polder conductivity values exceeded 4.0 mmho/cm. In terms of moisture available to the rice roots, the osmotic potential has to be added to the matric potential. The osmotic potential is larger than the matric potential. At 2.2 mmho/cm, corresponding with pF 2.8 or a water height of about 900 cm, an increase of 20 cm water height due to the matric component is negligible. Locally, however, higher values of matric suction and of conductivity may occur.

Presumably in the wet tillage, the uptake of soil moisture and uptake of nutrients by mass flow will be less well distributed over the top 30 cm than in other tillage treatments. Locally concentrations of substances harmful to the rice roots may be higher, and back-diffusion will occur of ions excluded by roots.

6.8 MECHANICAL-STRUCTURAL STABILITY

Structure is destroyed by puddling and by water saturation. Wet tillage reduces the soil almost entirely to a mud. During drying, restructuring occurs. In other tillage treatments, inundation destroys part of the structure by air explosion. Moreover, flooding decreases structural stability during the rice-growing period.

These effects were measured by the wet-sieving and the end-over-end-shaking procedure (3.1). By the wet-sieving procedure, the easily suspendable soil material was measured. The fraction of dry mass going into suspension after sieving for 30 minutes of the whole sample is given in Table 39. The suspended fraction includes two components: (1) already suspended mud in the soil; (2) soil aggregates broken by the sieving procedure.

Table 39. Percentages of particle dry weight going into suspension according to the wet-sieving procedure.

Wet tillage		Dry/wet tillage		Dry tillage		Zero tillage	
median	range	median	range	median	range	median	range
43	31-78	56	52-72	37	16-48	32	33-45

Table 40. Percentages of stable aggregate dry weight in the end-over-end shaking procedure.

Wet tillage		Dry/wet tillage		Dry tillage		Zero tillage	
median	range	median	range	median	range	median	range
69	64-72	70	67-75	73	71-74	74	70-76

The mass fraction of soil suspended by the wet-sieving method was related to the structure-destroying activity of puddling. With dry and zero tillage less went into suspension than with dry/wet tillage. With wet tillage, there was a wide range. The lower values were due to concrete-like restructuring during drying after post-seeding surface drainage. This firm structure can partly withstand destructuring by the wet-sieving forces. Stability of the more stable soil fragments, which survived the destructive forces in the wet-sieving procedure, were exposed to the end-over-end shaker stability measurement. The 1.0-2.0 mm fraction obtained by the wet-sieving procedure was used (Table 40).

The aggregates of the 1-2 mm fraction did not differ much in stability. Median values were lower for wet and dry/wet tillage, but their ranges overlapped these for dry and zero tillage.

In the field, part of the aggregates went into suspension during puddling. Aggregates remaining were only slightly less stable than those in plowed soil, which, however, dried intensively after plowing. Structural instability is, however, more dependent on the less stable soil particles than on the stable ones. Compaction as a result of structural instability occurred with wet and dry/wet tillage, according to data for bulk density and dehydration.

Observations of matric suction during soil moisture extraction (6.4.) suggested the collapse of pores in the wet tillage sample. This observation is related to the less stable structure in the puddled tilled layer after wet tillage.

SUMMARY CHAPTER 6

1. Soil tillage influences the moisture content of the soil:
   -before flooding. Intensive drying down to 10% moisture occurs only after dry plowing (dry and dry/wet tillage) without dry plowing the moisture de-

creases to 35-60% depending on the weather mainly.

- before sowing. The moisture content of the soil after flooding increases to 65-70% with zero tillage, to 70-75% with dry tillage, with puddling it increased to 80% at dry/wet tillage and to 80-110% at wet tillage.
- after sowing. The soil moisture content of the puddled layer decreases by evaporation and root extraction. The decrease is irreversible and is accompanied by a denser packing of the clay particles. After previous drying down to 10% moisture the saturated soil continues to increase its moisture content by slow expansion of the clay lattice.

2. The intensive drying of the soil before flooding influences:
   - dehydration curves, as drying causes restructuration.
   - stability of the soil aggregates, which is increased only slightly.
3. The soil structural arrangement resulting from tillage in the tilled layer shows an increased destructuration of the soil mass in the order of zero, dry, dry/wet and wet tillage, and influences:
   - soil moisture contents, which increase in the order of soil destructuration (zero 70%, dry 70-80%, dry/wet 75-85%, wet 80-100%).
   - bulk density, decreasing in the order of destructuration, with high values for zero tillage due to compaction.
   - dehydration curves showing increased moisture release in the range up to pF 2.7 in the order of soil destructuration, with the exception of dry/wet tillage due to a slight compaction.
   - amounts of soil moisture extracted with time by applying a constant suction decreases in the order of the presence of large cavities: dry, dry/wet, wet and zero tillage.
   - water permeability decreased in the wet tilled layer to values too low to be measured; after dry tillage it was over 1m/day.
   - electrolyte concentration in the soil moisture measured as electrical conductivity decreased with easier transport or exchange of solutes between the flood water and the slightly salt subsoil, influenced by cavity dimensions and occurrence of sedimented layer in the order of wet, zero, dry/wet and dry tillage.
   - the stability of the soil mass was low in the puddled tilled layer, where pores collapsed after applying suctions in the range of about pF 2.7. The percentages of the soil mass that went into suspension with wet sieving increased with increased destructuration at tillage. Only with wet tillage restructuration, due to irreversible moisture loss, resulted in less suspension material than with dry/wet tillage.

4. The water permeability in the 10-50 cm layer decreased with 20 years of rice cultivation on a formerly swamp soil from 1-4 m/day to 0-70 mm/day. Permeability decreased in the order of present type of tillage of increasing puddling intensity: dry tillage (8-70 mm/day), dry/wet tillage (1-14 mm/day), wet tillage (0-3 mm/day). The permeability of the 50-100 cm zone was not influenced by reclamation or present tillage (0.1-2 m/day).
5. Rice plants had to take up soil moisture against a matric and an osmotic potential, during the first part of the growing season, when root growth was downwards. The formation of a root mat after stem elongation enabled the uptake of water from the floodwater.
   -The osmotic potential measured as electrical conductivity increased with depth with respective average values of 1.0, 1.5, 3.0 and 3.9 mmho/cm at 25 °C at 0-5, 5-10, 10-15 and 15-20 cm depth. Expressed in pF values, they range from 2.3 to 3.0 and exceeded the level of matric potential.
   -The matric potentials were calculated according to a model and measured in the field.

   Piezometer measurements showed matric suctions only to occur in the 10-30 cm zone with wet tillage, while at other depths and with other tillage treatments only a lowering of the water pressure to maximum zero was obtained. Tensiometer measurements showed a matric suction of 20 cm water height with wet tillage at 20 cm depth.

   Calculated matric suctions were based on a model inserting rooting depth, water permeability and transpiration rate, and amounted to 65 cm water height at 50 cm depth with wet tillage. Down to 20 cm, the calculated and measured data coincide; below this depth they deviated largely, presumably due to an effective rooting depth for water extraction of only 20-30 cm instead of the postulated 50 cm, and due to non-steady transpiration of rice plants during day and night.
6. Water moves downward from the floodwater into the soil with decreasing volume in the order zero, dry, dry/wet and wet, according to piezometer measurements. Water levels inside the tubes deviated from the floodwater level increasingly in the same order, showing water extracted by plant roots to be only partly replenished by floodwater. The piezometers opening in the 10-50 cm zone did not react to floodwater movements, indicating a lack of contact presumably by gas blockages in pore widening and collapse of pores.

   Recently reclaimed rice soils showed, contrary to data from a 20 years old reclamation, a coincidence of water levels inside the piezometer tubes with the floodwater level independent of the type of tillage. This is due to the still high permeability in the 10-50 cm layer and the presence of peat residues in the tilled layer, which make the puddled layer more permeable.

Hydraulic potential probes indicated the presence of over and under pressure to vary within the soil from place to place. Overpressures caused by gas formation assumes air locks in pore widenings.

7 Chemical properties of soil

Along with its effect on physical properties, tillage influences the chemical properties of soil. Previous experiments showed that in general rice responds favourably to nitrogen fertilizer. The response however is irregular and presumably dependent on soil conditions including tillage. The responses of rice to phosphate and copper are less evident. Therefore in studies of chemical properties emphasis was placed on the behaviour of nitrogen in the soils of the Wageningen Polder. Section 11.3 gives some data on phosphate too.

Chemical investigations are usually on dried and ground samples. Under the present circumstances, this has two drawbacks: (1) for study of the influence of tillage on chemical properties, soil structure as in the field has to be preserved; (2) in rice cultivation, chemical differences brought about by variations in tillage are partly due to the state of reduction of the soil. Consequently the investigations had to be carried out on undisturbed soil samples.

As in the cultivation of lowland rice available nitrogen mainly refers to ammonium, the quantities of this component were estimated as exchangeable ammonium by shaking samples of reduced soil with potassium chloride solution, 1 mol/litre (7.1). In addition, soil moisture was extracted from undisturbed field samples by applying suction. The extracted soil moisture was analysed for iron, sodium, potassium, calcium, magnesium and sulphate. This procedure deviates from the usual one, in which soil moisture is obtained from potted rice soils by gravity flow (7.2).

7.1 MINERALIZATION OF NITROGEN COMPOUNDS

In general, recommendations on fertilizer use are based on the results of both soil chemical analysis and fertilizer trials. For nitrogen, however, only the trials are usually considered because of the difficulty in obtaining reliable estimates of availability of soil nitrogen. Unpredictable soil-moisture and temperature conditions exert a strong influence on the quantity of nitrogen resulting from the mineralization of organic matter. Laboratory incubation techniques involving decomposition of organic matter by bacteria are usually carried out under optimum conditions for the bacteria and the outcome, when transferred to field conditions, usually leads to unrealistically high predictions of easily minerabizable and, hence potentially available nitrogen.

Nevertheless, in temperate regions, reasonably successful attempts have been made to predict the amounts of available nitrogen at the start of the growing season. They are based on simulation techniques, in which use is made of knowledge or records of previous weather, and of nitrogen mineralization and transport (Ferrari, 1973). In the tropics, even more than in temperate regions, weather forecasting is, however, so uncertain (especially about rainfall distribution intensity) that its usefulness in predicting amounts of available nitrogen is questionable. In the coastal plains of Surinam, the type of tillage distinctly influences the intensity of the green colour in rice foliage, presumably by the amount of available nitrogen, as was suggested by N fertilizer experiments. To test this hypothesis, soil samples from submerged ricefields bearing crops ranging in colour from pale yellow to green were analysed for exchangeable ammonium. The differences were not significant, so that the level of exchangeable ammonium seems not to be related to the amount of available nitrogen during the growing season.

Consequently, the idea comes to mind that perhaps the rates of ammonium produced by mineralization of soil organic matter during the growing season are more directly related to the amount of potentially available nitrogen. Consequently, attempts were made to measure the ammonification rates in flooded soils tilled in different ways, excluding the effect of uptake by plants. This method will be referred to as field incubation.

In addition, ammonification was studied in pots in which the various tillage treatments were simulated, and growth and nitrogen nutrition of rice were measured. This experiment will be referred to as pot incubation.

For the procedure of sampling, chemical analysis and data expression, see 3.1.

7.1.1 Field incubation method

In field incubation, plastic tubes (20 cm long, 10 cm in diameter) were driven completely into the soil in between rice plants. The surrounding rice plants were unable to take up nitrogen from the soil inside the tube, so that differences in the nitrogen content inside the tubes and close to them had to be attributed to uptake by the plants. This method ensures that environmental conditions do not differ much from those immediately around the tube.

Due to the impermeability of the subsoil, loss of ammonium by percolation is negligible. The soil inside the tube will be referred to as uncropped soil; the soil outside the tube as cropped soil.

At all sampling dates, the amounts of ammonium in the cropped soil outside the tubes were found to be almost the same for all tillage treatments. This means that the growing crop takes up all ammonium formed during the growth but is unable to deplete the soil beyond a certain minimum characteristic of the soil. This minimum was already present at the start of the experiment. For this reason, it did not make any difference whether the reference samples were taken at the start or at the end of the incubation experiment.

For all treatments, the content of *exchangeable ammonium in the cropped soil* ranged from 25 to 52 mg per kg of dry soil. Higher values occurred only with poor growth after damage by rates with death of seedlings, and with young plants (up to twenty days old) when their uptake capacity was still low. Thirty days after sowing, the values ranged from 26 to 29; 50-60 days after seeding, they had slightly increased to between 34 and 52. Thereafter values dropped to 25-27. The changes and variations can be considered to represent dynamic balance between ammonium production and uptake by roots. Rate of uptake was greatest in the early stage of plant growth; thereafter it decreased. The rate of ammonium production gradually decreased during the growing season, so that 50 to 60 days after sowing the rate of ammonium uptake had decreased more than that of ammonium production. At this stage of development of the rice, the primary root system decays and a secondary system develops as a superficial layer of fine roots, partially on the soil surface (8.3). Thereafter, the rate of ammonium production dropped to below the rate of uptake.

The rate of uptake by the root system influences the ultimate balance between production and uptake. In the field, this balance was found to be at a level twice as high as in the soils of the pot experiments where it was reached at values of 11-14. These low values can be accounted for by the dense root system in pots, shortening the path taken by the ammonium from its place of production to the place of uptake.

Healthier roots in pots may intensify the withdrawal of ammonium from the soil, thus steepening the concentration gradient, increasing the diffusion rate and, thus, more heavily depleting the soil.

There were no effects of tillage treatment in pot and fields on the level at which a balance is reached between production and uptake of ammonium. Attempts to evaluate root density and health did not succeed (8.3). Hence, no direct relation between the level of the ammonium balance and root properties could be established.

The increase in *exchangeable ammonium in uncropped soil* inside the incubation tubes that had undergone different tillage treatments are presented in Figure 44. The data refer to duplicate measurements obtained from soils in tubes 45 cm long. Incubation started 17 days after sowing. The soil samples were analysed by a method somewhat different from that given in 3.1 so that the two sets of data for ammonium are not comparable. The effect of tillage is most certainly pronounced in the surface samples and the production of ammonium is promoted most strongly by dry tillage. A period of surface drainage on Days 13-17 interrupted ammonium production in dry and wet tillage treatments. Rainfall during this period retarded the drying of the surface, so that no intense nitrification was possible. The interruption in the rise in amount of ammonium might be explained by postulating denitrification, the formation of escaping gaseous inorganic nitrogen compounds.

Apart from the effect of the 4-day surface draining period, dry and dry/wet tillage both gave constant rates of ammonium production. With wet tillage, this rate was less constant: after a slower rate during the first 20 days, the rate

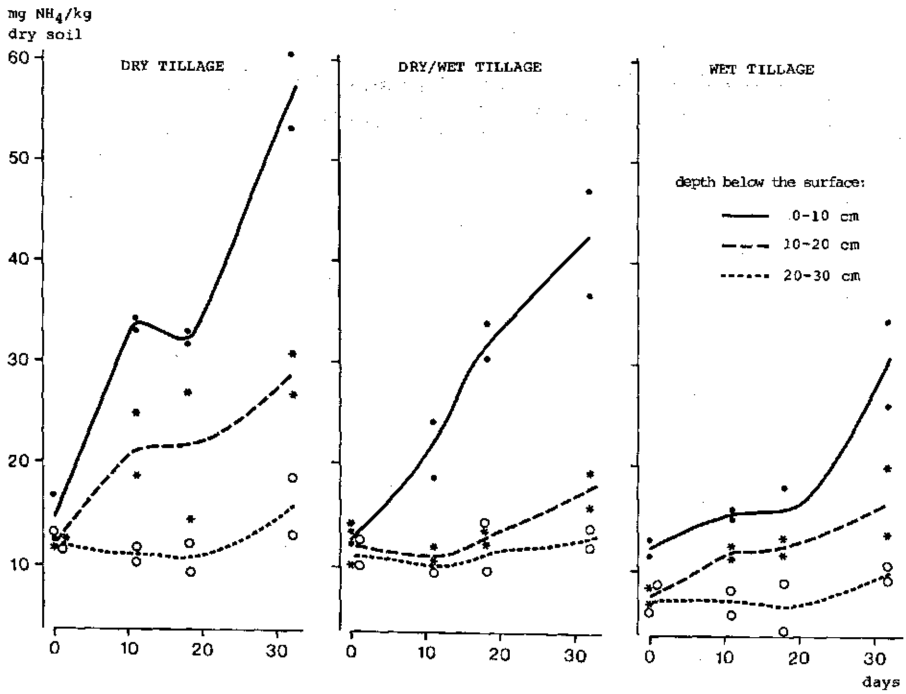


Figure 44. Increase in exchangeable ammonium with incubation in the field through mineralization of organic matter after different tillage treatments.

was similar to that for the other tillage treatments.

For two of the three treatments, the increase in ammonium at depths below 10 cm was negligible. Only with dry tillage was a notable amount of ammonium produced. For that reason, measurements of ammonium production were restricted to the top 7.5 cm in subsequent trials. They were made over periods ranging from 10 to 25 days. The data were expressed as rates of ammonium production per area in kg ha (30 days).

Besides having information on ammonium levels in the uncropped soil cores as compared with the cropped soil, it is important to have knowledge on the ammonium production in the reclaimed soil as compared with that in the original swamp.For that purpose, two plots in an existing reclamation trial were used. These plots,each 6 ha in area, were embanked. One was drained, the other was kept flooded, both for a period of three consecutive growing seasons (1½ year). They were not tilled. The vegetation of the flooded treatment object was as usually found in a swamp and of the drained treatment was usual for land derived from it.

Ammonium production was measured at the end of the third season and over a period of 30 days amounted to 1-2 kg/ha (flooded area) and 16 kg/ha (drained swamp). The former is very low, as compared to those of the tillage treatments in the older reclamation (Fig. 44). In the drained swamp soil, conditions for nitrogen mineralization were probably optimal, taking into account that oxidation of ammonium to nitrite and nitrate and subsequent leaching or denitrification in the permeable soil would have occurred during the collecting period.

In some trials, the production of ammonium in lowland rice soils was measured in consecutive growing seasons (the long rainy season and the subsequent short one). The range of values obtained for the four tillage treatments are given in Table 41.

Table 41. Ranges of ammonium production for two periods in the growing season as affected by tillage

Period	Ammonium production (kg N/ha[1] in a 30 day period)			
	wet tillage	dry/wet tillage	dry tillage	zero tillage
15- 40 days after sowing	10-15	15-28	25-32	2-16
70-100 days after sowing	2- 6	2-12	9-13	1- 6

1 Average data from 5 trials in two seasons

The rate of nitrogen mineralization for the different soil treatments was consistent for the two seasons. The uniformity of ammonium production depended on the uniformity of the tillage treatment. The range was low for dry and wet tillage, higher for dry/wet and highest with zero tillage.

For ammonium production, the tillage treatments arrange themselves in two groups. One group, comprising zero and wet tillage, showed a maximum ammonium production of 16 kg N ha^{-1} (30 days)$^{-1}$. The puddling treatment leads to an ammonium production up to this level. With zero tillage, a similar level may be obtained in specific circumstances at specific places. The other group, comprising dry and dry/wet tillage, showed a maximum ammonium production of 32 kg N ha^{-1} (30 days)$^{-1}$. Dry plowing of soil appears to promote ammonium production; the subsequent wet seedbed preparation counteracts this effect to various extents.

The rates of ammonium production in soils under different tillage treatments in the older reclamation may be compared with those in the swamp. The drained swamp soil had a rate corresponding with that of the dry tillage treatments in the beginning of the rice-growing season. The flooded swamp soil had a rate that was exceeded by that of soil in all tillage treatments throughout the rice-growing season. Therefore in flooded soils ammonium production is promoted by tillage. In an aerobic drained swamp soil the rate of nitrogen mineralization is, however, much larger than that in a dry-plowed flooded rice soil. In the drained swamp soil nitrate production would have to be added to the production of ammonium to account for the total production of inorganic nitrogen.

Within each of the tillage treatments, certain variations are possible that may influence the rate of ammonium production. To investigate these effects, soil samples of the top 7.5 cm were taken 10 days after flooding but before the rice was sown (data from Field Trial 4 described in 3.3.4; yield data are presented in 8.3). The contents of NH_4 in Table 42 are those present at the moment of sampling, not those produced during a certain period, unlike the previous tables.

The differences among the treatments were not significant, but they might have been larger if samples had been taken at a later date. Because of the fixed date of sowing, this was not possible.

Table 42. Effect of variations in the main tillage treatments on the contents of NH_4 in the soil.

Ammonium levels in soil (mg NH_4 per kg dry soil)															
Wet tillage				Dry/wet tillage				Dry tillage							
number of puddling treatments[1]				intensity of puddling after dry plowing[2]				number of plowing treatments[3]				depth of tillage, in cm[4]			
0	2	4	6	beam on dry soil	beam on flooded soil	mudroll once	mudroll twice	0	1	2	3	0	5-9	10-15	15-20
35.6	41.0	37.5	34.4	49.9	49.4	49.4	53.9	33.8	36.2	40.9	38.5	30.3	45.7	40.6	37.6

[1] Least significant difference for Note 1, 18.2; Note 2, 12.1; Note 3, 11.1; Note 4, 15.9.

7.1.2 *Pot-incubation experiments*

At the end of a growing season, the upper portions of the 7.5 cm layer of flooded soil were dug out and transferred to 10-litre pots. Two soil structures, namely clod and mud structure, were established at three levels of soil moisture, at previous drying 70%, 40% and 10% (mass/mass).

After attainment of the 70% and 40% moisture levels, clods were obtained by hand, after which the soil was submerged. To obtain a mud structure, the soil was submerged and completely puddled. The 10% level was obtained by allowing soil in a clod structure at 50% moisture to dry out further till 10% moisture. The mud structure with a moisture content of 10% before flooding was obtained by puddling clods, which were dried to 10% moisture.

In two pot experiments (Nos. 2 and 3), nitrogen mineralization was studied. In Experiment 2, ammonium was measured after a flooding for 30 days. In Experiment 3 (in another season), the period of flooding was only 10 days. The results are presented in Table 43.

In both experiments, ammonium contents after puddling were higher than those after clod-making. Without drying (70% moisture), puddling stimulated the production of ammonium; with partial drying (40% moisture), the differences

Table 43. Ammonium in potted soil after clod-making and after puddling at three moisture contents before flooding

Moisture content before flooding	NH_4 present after flooding (mg NH_4/kg dry soil)			
	experiment 2		experiment 3	
	after clod-making	after puddling	after clod-making	after puddling
70%	44	53	29	34
40%	47	54	40	41
10%	97	138	69	78

Experiment 2, effects and interactions highly significant ($P < 0.005$); Experiment 3, significant ($P < 0.025$).

between clod-making and puddling for ammonium production became smaller. Drying to 10% moisture markedly increased ammonium production.

Afterwards, on the pots of Experiment 2, rice was grown. At 34, 55 and 72 days after sowing, ammonium contents were found to be 12, 14 and 11 mg per kg dry soil, respectively. No effects of soil drying before flooding or of soil structure on ammonium production were present. These values are very low in comparison with those encountered in soil samples from the field (25-52 mg NH_4 per kg dry soil). The much higher root density in the pots may account for this difference.

7.2 SOLUTES IN SOIL MOISTURE

Several research workers have used chemical analysis of soil moisture to characterize the environment of rice roots. Ponnamperuma (1963) brought soil in a granulated condition, stabilized this structure by adding bentonite, and extracted soil moisture at gravity flow. In the present experiments, other soil structures than the granulated ones are used, and the stabilizing agents were avoided. With wet and zero tillage, however, no soil moisture could be extracted by gravity flow. Consequently suction had to be applied. For this purpose, soil cores were collected in cylinders in the field and taken to the laboratory. When extraction started, the soil was still in a reduced state, but, during the process, oxidation was not prevented (for further details, see 3.1). The matrix suctions measured in the samples extracted and the quantities of soil moisture extracted with time are given in 6.4; electrical conductivity has been described in 6.7. In the extracted moisture, iron, potassium, sodium, calcium, magnesium, and sulphate were measured to detect any differences in concentrations related to differences in tillage.

The data in 6.7 show that conductivity increases with depth down to 20 cm. Parallel with this, the concentrations of K, Ca, Mg and Na rise, but the Fe concentration increased down to 15 cm and sharply decreased hence to 20 cm. Differences in chemical composition due to variations in tillage were most pronounced for Fe and K.

Figure 45 shows that, for zero tillage, the iron in the extract was very low (less than 4 mg/litre) at all depths. After wet and dry/wet tillage, large variations in iron occurred at the start of the growing season; later, for all treatments except zero tillage, iron was high at 5-15 cm depth (in general 10-20 mg/litre). In the top 5 cm, dry tillage caused the iron to be initially low, but values increased during the growing season to levels encountered in the wet and dry/wet tillage treatments.

Potassium in soil moisture was found to decrease at all depths during the growing season (Fig. 46). After dry and wet tillage, the concentrations in the top 5 cm were too low to be measured accurately. With zero tillage, potassium concentration also decreased, but the values were generally higher than for other tillage treatments. For all tillage treatments, potassium in soil moisture increased with depth.

Other nutrients (calcium, sodium, magnesium) in soil moisture varied only slightly between tillage treatments; no trends could be observed. The sulphate values did not show any relation with tillage treatments or depth; they ranged from 20 to 40 mg SO_4 per litre, with some peak values (up to 70 mg/litre) at the start of the growing season.

Differences in nutrient concentration in soil moisture of plots treated in different ways may correspond with differences in the physical conditions in the tilled layers or with chemical differences arising after flooding plots previously dried in different ways. In addition, an increased ammonium production (7.1) induces faster growth, so increasing nutrient withdrawal. Conversely, the higher potassium values in the soil moisture of the zero-tilled plots may have been a consequence of poorer growth.

The absence of easily decomposable organic material as stubble and weeds mixed with topsoil, as found with zero tillage, results in low iron concentrations in soil moisture. The absence of easily decomposable organic matter deprives soil micro-organisms of the necessary energy sources for their heterotrophic life cycle, in which trivalent iron, used as electron acceptor, is re-

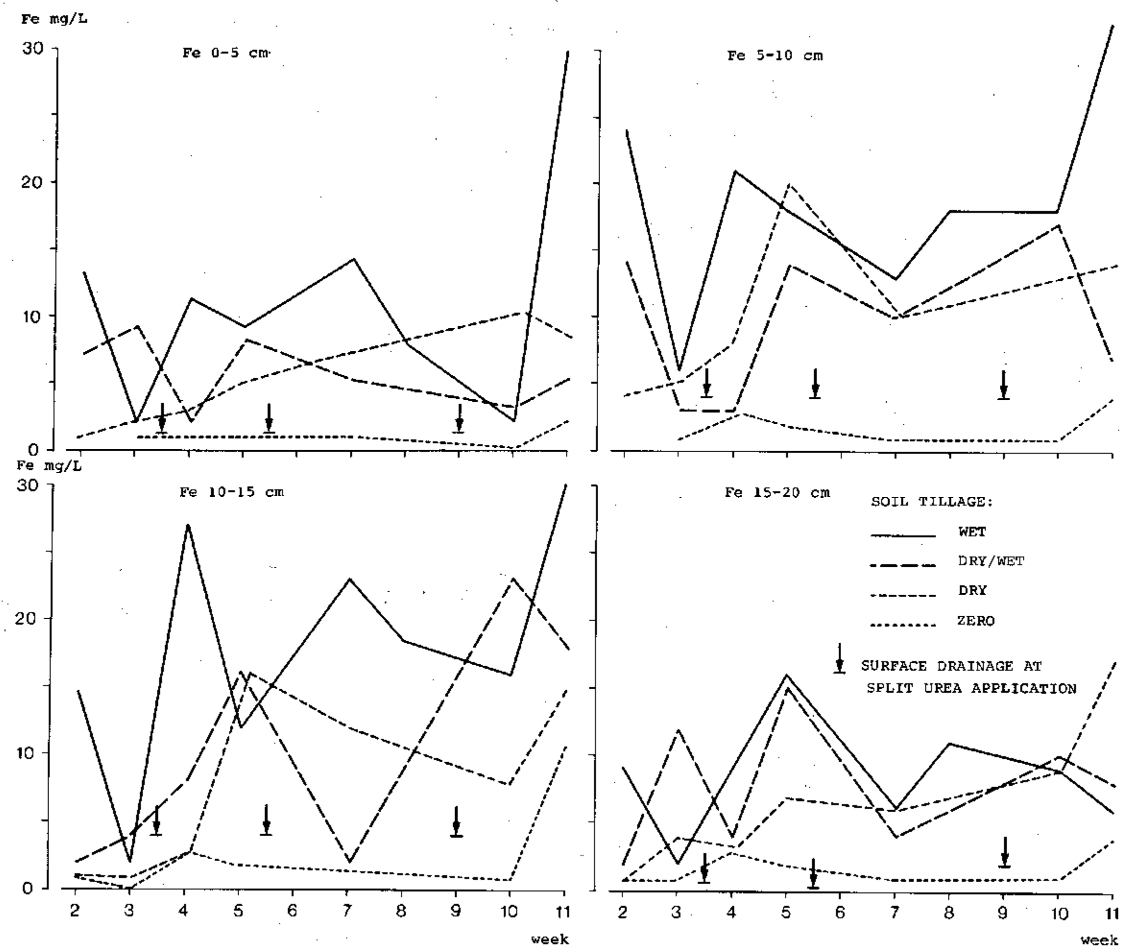


Figure 45. Iron in the soil moisture extracted after different tillage treatments.

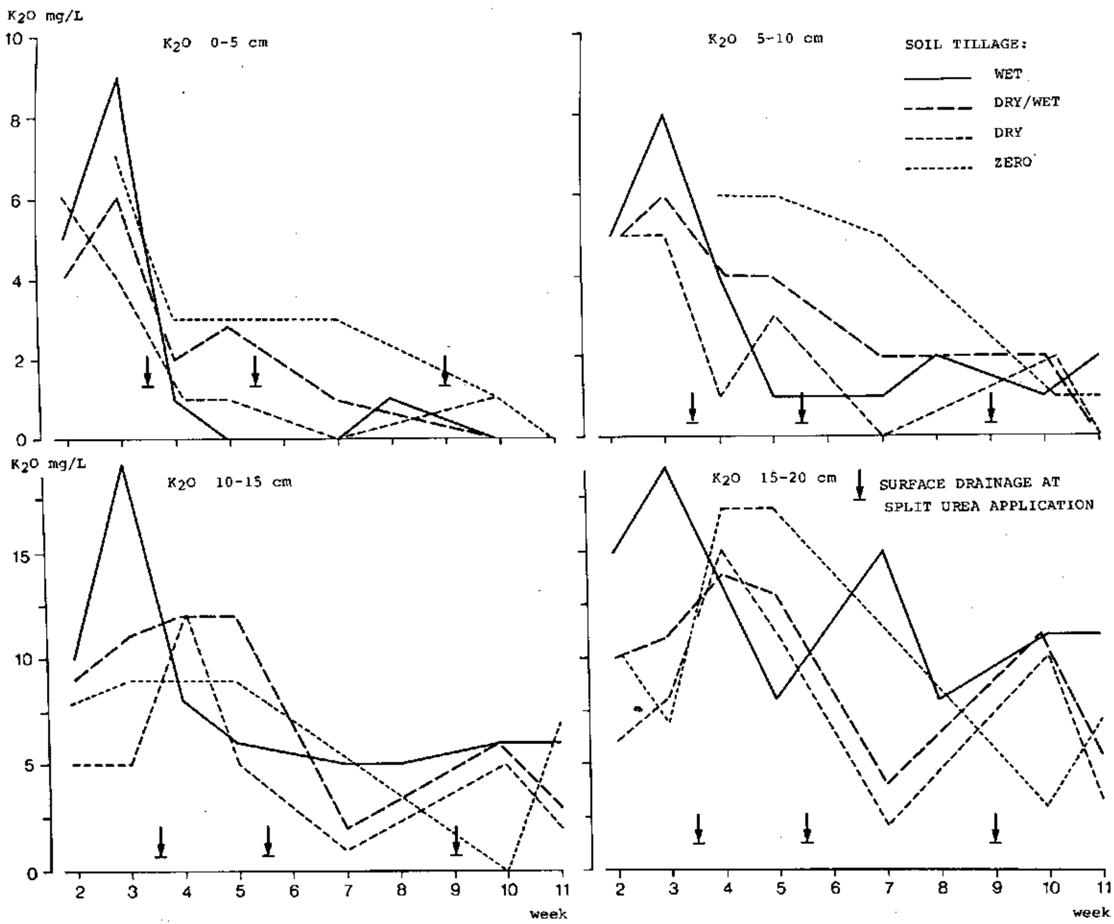


Figure 46. Potash in the soil moisture extracted after different tillage treatments.

duced to the soluble divalent form.

In general, measured soil moisture components tended to increase with depth, except for iron, whose concentration decreased to a depth of 15 cm. The absence of easily decomposable organic matter is likely to prevent the reduction of trivalent iron.

Since tillage influenced the chemical composition of soil moisture in the present experiment, the use of soil stabilizers and of granulated soil, as practiced by Ponnamperuma and other investigators, must be questioned. Such a question can be raised especially when laboratory data from granulated soil samples are extrapolated to field conditions where puddling is practiced.

SUMMARY CHAPTER 7

1. In this chapter, it was shown that the rate of mineralization of organically soil nitrogen in submerged soils can be determined by measuring the amount of ammonium produced in incubated soil samples kept under field conditions in the absence of roots that would absorb part of the ammonium produced. The impermeable subsoil underneath the cores of incubated soil prevented the ammonium produced from being lost by percolation.
2. Besides being influenced by weather, the rate of mineralization of soil organic nitrogen is affected by the type of tillage practice. In comparison with the low rate of mineralization in a swamp soil (1 kg of NH_4 N produced in 30 days), the mineralization ranged from 2 to 35 kg NH_4 N in 30 days in submerged soils, depending on the type of soil treatment before the growth of lowland rice.
3. The rate of N mineralization is affected by the type of soil treatment in two ways: (1) by the degree of drying before flooding, and (2) by the type of soil structure created by tillage. A reduction in soil moisture content to 10% before flooding enhances N mineralization by a factor of 2.5 relative to the mineralization found in soils that had dried to 40-70% moisture.
4. In the absence of soil drying to less than 30% moisture before soil tillage, the practice of puddling stimulates soil N mineralization only by a factor of 1.1 to 1.4 relative to the values obtained with dry tillage. Under practical conditions, soil drying down to 10% is only reached when clods are produced in a dry tillage operation carried out on a soil already dried to a moisture level of 40 to 50%.

5. Under field conditions, nitrogen mineralization is high when clods are formed in a surface-drained soil (dry and dry/wet tillage), and low when clod formation is deleted (wet and zero tillage, Fig. 44).
6. The average amounts of NH_4 N produced per ha in 30 day-periods in soil that had undergone the various tillage treatments, for the first and second half of the growing season, respectively, were: dry tillage 28 and 11 kg, dry/wet tillage 21 and 7 kg, wet tillage 12 and 4 kg, and zero tillage 9 and 3 kg.
7. The variability in NH_4 content among samples of incubated soil is high for the tillage treatment that does not lead to a homogeneous tillage layer (dry/wet tillage treatment) or in the absence of any tillage treatment (zero tillage).
8. In the soil outside the cylinders, the soil ammonium level was determined by the rate of mineralization of soil organic nitrogen and by the withdrawal of ammonium by the rice plants. During the growth of the plants, a relatively stable ammonium level was reached. The level was independent of the type of soil tillage and was determined by the rate of production of ammonium during the various stages of the growing season and by the intensity with which NH_4 is withdrawn by the rice plant during the various stages of plant development.
9. The type of tillage influenced the chemical composition of the extracted soil moisture. The level of total iron in the soil moisture depends on the availability of easily decomposable organic matter, and is low at zero tillage. The level of potassium in the soil moisture was related to the plant root withdrawal intensity, and was high at zero tillage.
10. The chemical composition of soil moisture obtained from potted granulated soils stabilized with benthonite may deviate from the puddled field soils. Use of chemical analyses of stabilized granulated soils to predict the behaviour of puddled field soils may lead to mistakes.

8 Aspects of plant growth

In this chapter, attention will be paid to the influence of soil tillage on rice growth. Growth aspects can be distinguished into aspects of nitrogen nutrition, crop density, and rooting habits. Nitrogen nutrition is considered to reflect some of the relationships between certain soil characteristics (Chapter 7) and plant growth. Direct relationships of other soil characteristics than exchangeable ammonium with rice growth are not so easily evaluated. For convenience, information about nitrogen availability and absorption by rice was obtained from pot experiments with some information from field trials (8.1). The absorption of nitrogen by rice grown in the field is dealt with more thoroughly in Chapter 9, dealing with nitrogen fertilization.

The influence of soil tillage on crop density was studied in field trials. Section 8.2 discusses the results of an experiment on the effect of seed rate and rate of nitrogen fertilizer on rice yield. Section 8.3 gives some information on the rooting habits of rice.

8.1 EFFECTS OF PRESENT SOIL STRUCTURE AND PREVIOUS SOIL DRYING

The effect of soil tillage on rice growth and rice yield has at least two components (Chapter 7). One is related to the differences in soil structure resulting from variations in tillage treatment, the other is related to the effect of the various soil tillage treatments on the drying process in the intercrop period before flooding, henceforth called previous soil drying. Under field conditions, the two components usually interact. In pot experiments, the main effects and their interactions can be studied.

In general, it is difficult to observe any direct relationship between differences in soil characteristics and plant growth, but the effect of soil tillage on one of the soil characteristics, namely N mineralization, is readily observed. For that reason, in the pot experiments the effects of soil structure and previous soil drying on rice growth and N uptake by the rice plant are tested by using N mineralization as criterion. In the previous chapter it was shown that previous soil drying increased mineralization (7.1).

The present chapter presents the effect of an increased intensity of previous soil drying on rice growth, as studied in Pot Experiment 1, and thereafter the question of how far the drying effect can be compensated for by applying N fertilizer in absence of drying. This question is of practical importance, since weather conditions often prevent dry plowing and subsequent soil drying. The question has two aspects: (1) whether the effect of dry plowing can be compensated for with N fertilizer; (2) whether the effect of soil structure on crop yield is absent if the effect is compensated.

To answer these questions, factorial experiments on the effects of N fertilizer were carried out in pots. The compensating effect of N fertilizer at different levels was tested in an experiment in which a split topdressing of N was employed (Experiment 2), and in an experiment in which N was applied as a basal dressing before planting (Experiment 3).

In field trials, only some of the tillage treatments related to the ones employed in the pot experiments were included.

8.1.1 Pot experiments

Unless otherwise stated, pot experiments included two soil tillage treatments resulting in a clod structure and a mud structure. Before treatment, the soils were allowed to dry to three moisture levels: 70%, 40% and 10% by weight. For the 70% and 40% moisture levels, the soil was left to dry as an undisturbed mass. For the 10% moisture level, the soil mass was first worked into clods when they had 40% moisture and were then allowed to dry down to 10% moisture. Thereafter, these clods were flooded and, subsequently were either left undisturbed or puddled totally to a mud structure.

In pot experiments, rice plants received more sunlight than plants growing under field conditions. In addition, grain setting of potted rice plants was quite irregular. Data on grain yields were not collected. Plant growth was investigated up to the flowering stage. Plants were cut at panicle initiation, at panicle differentiation, and at flowering. The yield data pertain to dry weight of shoots of three varieties. In Experiment 1, 2 and 3, the varieties were Apura, Acorni, and Awini, respectively. Because of differences in rate of development of these three varieties, the yield data in the three experiments represent different growth periods. For details of procedures, see Section 3.2.

Table 44. Effect of soil drying before flooding at clod structure on the number of tillers.

Type of drying	Soil moisture content before flooding	Number of tillers per plant
none	70%	5.4
open air	40%	5.8
open air	10%	6.1
oven	3%	6.8

8.1.1.1 Intensified previous soil drying at clod structure (Pot Experiment 1)

In this experiment, a fourth moisture level was included: 3% moisture obtained by drying clods with a moisture content of 10% in a forced-draft oven at 70 ^{o}C for 24 hours.

The effect of drying of a soil before flooding, on the development of rice plants grown on a flooded soil is presented in Table 44. There, plant growth is represented by the average number of tillers per plant.

Increased drying of the soil increased the number of tillers per plant. Soil drying increased N mineralization (7.1). The increased vegetative growth of the rice plant presumably results from increased N mineralization. In Experiment 1, N mineralization was not examined. It will be dealt with during discussion of the two subsequent pot experiments.

8.1.1.2 Split N dressings (Pot Experiment 2)

In this experiment, the influence of previous drying of soil in two structural conditions (clod and mud structure) on mineralization of soil nitrogen and on plant growth was investigated. Nitrogen fertilizer was introduced as an additional variable. Urea was added as a split dressing to the flooded soil 35 and 56 days after sowing. Two amounts of fertilizer were used per pots: 0 and 2 x 4.32 mg N (3.2). The rice plants were harvested 34, 55 and 72 days after sowing.

In Table 45, a summary is given of the results. The statistical significance of the main effects (type of soil structure, soil drying, and N fertilizer) and their interactions, on some soil and plant parameters are given. These parameters are the amount of NH_4 in the soil before sowing and the growth and N nutrition of the rice plants. Drying of the soil before flooding affected

Table 45. Levels of significance for the effects of type of soil structure, soil drying and nitrogen dressing, and their interactions, on soil and plant characteristics (Pot Experiment 2).

Stage	Soil and plant characteristics	Soil structure (1)	Drying of soil before flooding (2)	Nitrogen dressing (3)	Interactions 1 x 2	1 x 3	2 x 3	1 x 2 x 3
preplanting	NH_4 in soil	-	++	-	++	-	-	-
harvest at 34 days	dry matter weight of shoots	-	++	-	++	-	-	-
	% nitrogen of shoots	-	++	-	++	-	-	-
	number of leaves per pot	-	-	-	++	-	-	-
	number of stems per pot	-	+	-	++	-	-	-
harvest at 35 days	dry matter weight of shoots	++	++	++	++	-	-	-
	% nitrogen of shoots	-	-	++	-	-	-	-
harvest at 72 days	number of leaves per pot	+	-	++	++	+	+	-
	dry matter weight of shoots	++	++	++	++	-	-	-
	% nitrogen of shoots	-	-	++	-	-	-	-
	number of leaves per pot	++	++	++	+	-	-	-
	number of stems per pot	-	-	++	-	-	-	-

-=not significant; +=significance <5%; ++=significance <1%.

the amount of NH_4 in the soil before sowing, and plant characteristics after 34 days of growth (dry matter, N content of shoots, number of stems) after 55 days of growth (dry matter) and after 72 days of growth (dry matter and number of leaves). Differences in soil structure did not affect the amount of soil NH_4 before sowing, and the growth and N content of rice plants 34 days after sowing but, 55 and 72 days after sowing, did affect dry matter yield and number of leaves.

Interactions between the effects of soil structure and drying were present for almost all characteristics examined, except content of N in shoots after 55 and 72 days of growth and for the number of stems after 72 days of growth.

N fertilizer affected all plant characteristics after 55 and 72 days of growth. Only for the number of leaves, after 55 days of growth, was there an interaction between N application and soil structure, and between N application and soil drying.

Before the first application of fertilizer, plant characteristics were influenced mainly by drying and by the interaction between drying and soil structure. After the first application of N, the effect of this N on the yield characteristics became predominant, although effects of drying and soil structure, and their interactions continued to influence dry matter production and leaf number. However after the first N application, the N content of the shoot was influenced only by N fertilizer. Thus soil structure, soil drying and N fertilizer influenced the growth of the rice plant.

The influence of N fertilizer on the production of dry matter is shown in Figure 47. For both fertilized and unfertilized soil, the highest production was from pots containing intensely dried soils. Differences in production from undried and partially dried soils (70% and 40% moisture) were small or absent. As compared to non-drying, a partial drying of the soil before sowing slightly reduced dry matter production.

Differences in the N content of the rice shoots at the three harvest dates, resulting from the various treatments are presented in Table 46.

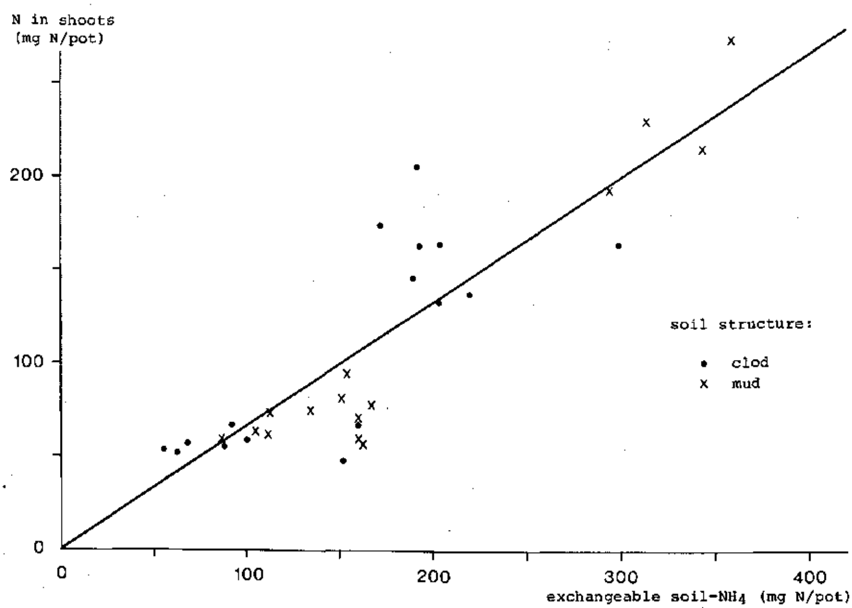


Figure 47. Effect of nitrogen application on dry matter production of potted rice plants, with different soil treatments.

Table 46. Effect of soil treatment and topdressing on the amount of nitrogen absorbed by potted rice plants during various growth periods.

Nitrogen top-dressing	Soil structure	Percentage moisture before flooding	Absorbed nitrogen (mg N per pot) during various time intervals (days after sowing)				
			0-34	34-55	55-72	0-55	0-72
Day 35	clods	70	54	201	219	255	474
and		40	61	168	218	229	447
Day 56		10	175	127	443	302	745
	mud	70	68	179	182	247	429
		40	75	176	152	251	403
		10	226	147	341	373	714
none	clods	70	54	21	5	75	80
		40	61	18	15	79	94
		10	175	- 9	- 20	164	144
	mud	70	68	32	- 15	100	85
		40	75	- 15	- 2	60	58
		10	226	- 79	- 2	147	145

Total N in the shoots after 34 days of growth increased with intensity of soil drying before flooding. At each level of soil drying, the mud structure always gave higher uptakes of N. From the 34th to 55th day of growth, omission of N fertilizer resulted in very small gains or sometimes even losses of N from the rice shoots. When N was applied on the 35th day, the uptake of N during the next 20-day period was inversely proportional to the amounts of N present in the plants at the moment of fertilizer application.

In the period between the 55th and 72nd day of growth, the amounts of N taken up from the fertilized soil were much larger for the most intensely dried than for the less intensely dried soils. In that period, the soils with the clod structure allowed more N to be taken up by the plants than did the soils with the mud structure, so that after 72 days of growth the plants on clods contained more N than those on mud, whereas after 34 days the situation had been just reversed.

Mineralization expressed in amounts of exchangeable soil NH_4 can be seen from Table 47. Differences in exchangeable NH_4 before planting and 34 days after sowing (27 days after planting) range from 10 to 100 mg N/kg dry soil, or 30 to 300 mg N per pot.

The N in shoots is significantly correlated with the amounts of exchangeable soil NH_4 before planting (Figure 48). The N accumulated in shoot ranges from

50 to 250 mg/pot. These values are significantly correlated with the losses of exchangeable soil NH_4 in this 27-day period. At the lower end of the range of mineralization, with a level of exchangeable soil NH_4 of 30 mg N/pot before planting, a continued mineralization of 20 mg N/pot thereafter is assumed. At the higher end of the range of mineralization, with a level of exchangeable soil NH_4 of 250 mg N/pot before planting, 50 mg N/pot cannot be accounted for in N accumulated in shoots. This discrepancy may be due to denitrification or to immobilization.

Up to 34 days after sowing, no fertilizer was applied to any pot. Thereafter, only the unfertilized pots remained available for studv of the relation between soil NH_4 and shoot accumulation of N. The increase in N in shoots between 34 and 55 days and between 55 and 72 days after sowing in the unfertilized pots was small or even negative. The content of NH_4 in soil was rather stable, from 9 to 11 mg N/kg dry soil. Mineralization was assumed to be almost absent

Table 47. Levels of exchangeable soil ammonia in potted soils at different moments during the rice-growing period (mg NH_4/kg dry soil).

Before planting	34 days after sowing	55 days after sowing	72 days after sowing
20-110	10	11	9

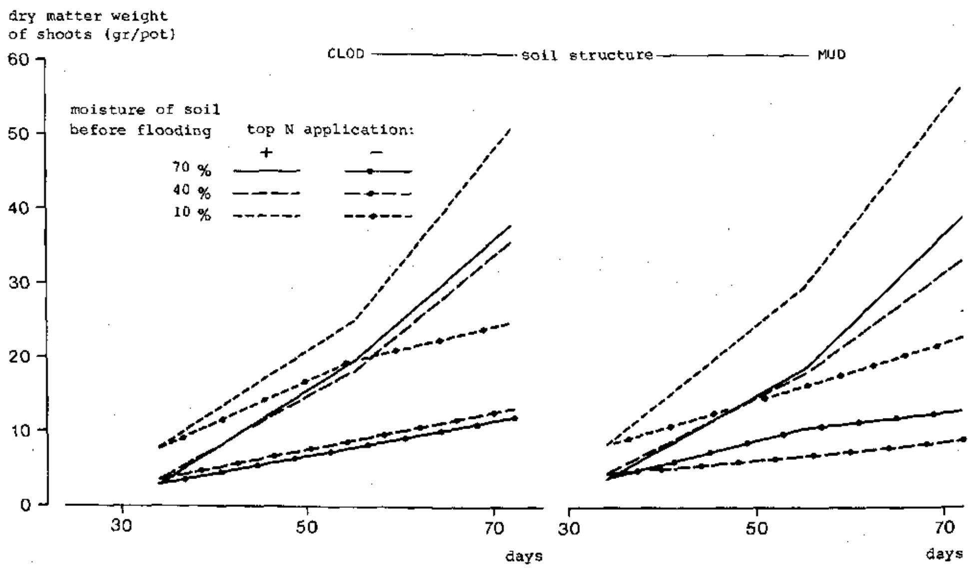


Figure 48. Relation between level of soil ammonium at planting and amount of nitrogen in the shoots of potted rice plants 34 days after sowing.

No differences between the soil treatments existed in effects on soil NH_4 and on changes in shoot N in these periods.

The differences in N absorbed by plants from fertilized and unfertilized soils, otherwise treated alike, can be considered to be an effect of fertilizer. When such a difference is expressed as a percentage of the amount of N applied, the resulting figure is called fertilizer efficiency. Data on efficiency are given in Table 48.

For the first dressing, estimates of efficiency were 30-60%. Increased soil drying decreased efficiency for soils with a clod structure, and increased it for soils with a mud structure. The efficiency of the 2nd dressing could not exactly be determined, since no plots were present in which the first dressing was absent and the second dressing present. By subtracting the value of the effect of the first dressing from that of the first and second dressings combined, the efficiency of the 2nd application can be estimated. The second dressing was utilized more efficiently than the first. Soils with a clod structure had a higher efficiency at all drying levels. For the clodded soil with previous soil drying to 10% moisture, the estimate of the efficiency of the second dressing exceeded 100%, so that a residual effect of the first dressing was present. Table 48 shows that no influence of soil structure on the efficiency of the dressings combined could be noticed, but that previous soil drying did exert an influence.

The differences in efficiency of fertilizer N for the first and second dressing might be related to the amount of N applied per pot. The amount of 432 mg N per pot corresponds with 130 kg urea per ha, which is twice the amount applied in the field. The capacity of plants to absorb nitrogen in the period between the 34th and the 55th day might have been limiting. However

Table 48. Increase in amount of nitrogen accumulated in rice shoots with nitrogen fertilization (over untreated plots) as a percentage of amount of nitrogen applied, for two single dressings and their combination, after various soil treatments.

Soil structure	Percentage moisture before flooding	First top-dressing	Second top-dressing	Both top-dressings
clods	70	45	54	50
	40	38	51	45
	10	30	116	73
mud	70	37	49	43
	40	48	39	43
	10	57	86	72

in the pot experiment, dry-matter production per unit of soil surface was six times the average value in the field.

At the flowering stage (72 days after sowing), fertilized plants had accumulated five times as much N as unfertilized plants, so that nitrogen in the shoots of fertilized plants was derived mainly from fertilizer. Independent of the fertilizer effect and of soil structure, intense soil drying before sowing stimulated N uptake, as can be seen in the N-accumulation data which are about 1.7 times higher for plants that had grown on intensely dried soils than for plants that had developed on less intensely dried soils. For these less intensely dried soils, the results in Table 46 show that the amounts of N in the shoots were usually lowered by partial soil drying. The influence of differences in soil structure on the amount of nitrogen in the plants at flowering was small (for clod over mud a factor 1.1).

Soil drying promotes the mineralization of organic nitrogen, thus raising the available quantity of soil ammonium (7.1). Table 46 shows that the influence of intense soil drying on N accumulation in unfertilized shoots was large up to 34 days after sowing, but that little further NH_4 was made available by the soil in the next period up to panicle differentiation. The differences in the amounts of N in shoots of unfertilized plants at flowering seemed mainly to reflect differences already present at 34 days after sowing. In contrast, the uptake of fertilizer N during the period before flowering (55th-72nd day) seemed enhanced by intense soil drying before sowing. It is rather peculiar that this intense drying hardly stimulated uptake of fertilizer N shortly after the first dressing. Uptake of N by plants on these soils was lower than that by plants growing on less intensely dried soils. Perhaps the high N content of plants on intensely dried soils was responsible for this poor response.

The effect of soil structure on N accumulation in rice shoots was strongest on the intensely dried soils during the first 34 days of growth, the mud structure being superior to the clod structure. In subsequent periods, the situation was somewhat reversed, so that at flowering on the unfertilized soils the effect of differences in tillage treatment was absent. On the fertilized soils, the initial advantage of a mud structure reverted to a slight disadvantage at flowering, so that an interaction existed between N fertilizer and soil structure. This interaction was responsible for the dependence of efficiency of N fertilizer on the type of soil structure (Table 48).

Comparison of Figure 47 with Table 46 reveals that dry-matter production and N accumulation in shoots were not closely related at the time of flowering, and that intense drying induced a higher N uptake but a lower dry-matter production on clodded soils than on soils with a mud structure.

The relationship between the amount of soil NH_4 in the soil at sowing, and the number of leaves per pot at tillering is shown in Figure 49. Above 200 mg of exchangeable NH_4-N per pot, the number of leaves per pot was no longer influenced by available soil nitrogen. The amount of N accumulating in young rice shoots beyond about 100 mg N per pot did not contribute to any further increase in number of leaves per pot (Figure 50). This large accumulation of

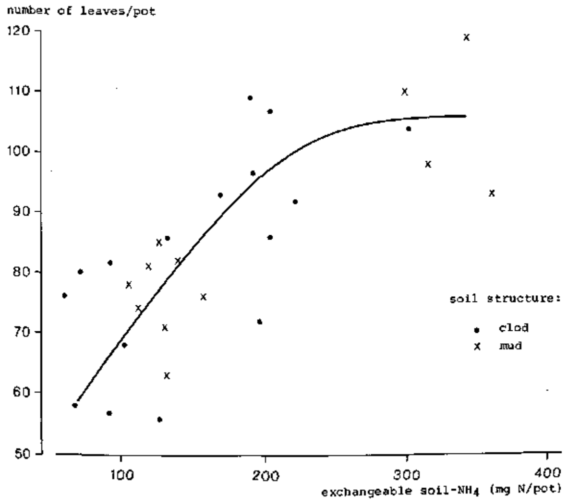


Figure 49. Relation between level of soil ammonium at planting, and number of leaves per pot 34 days after sowing.

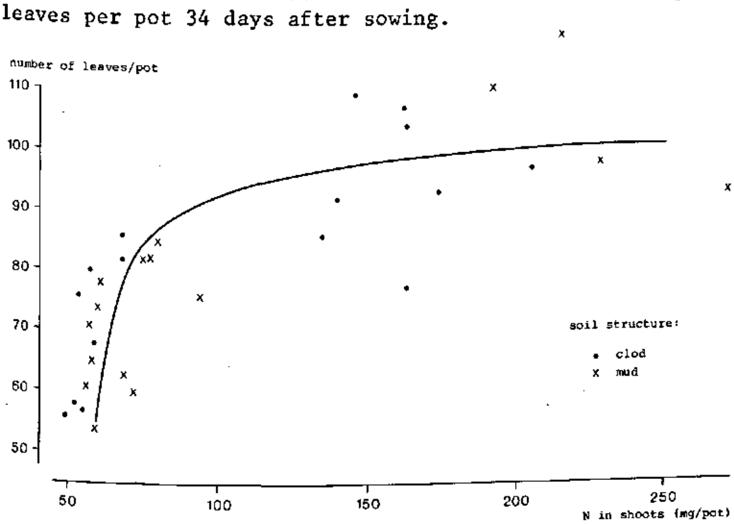


Figure 50. Relation between amount of nitrogen in shoots, and number of leaves per pot 34 days after sowing.

N could be luxury consumption of N. However, at later stages of development of the rice plant (Figures 51 and 52), such signs of luxury consumption are far less evident. Apparently, the initial rate of growth of the plants was insufficient to utilize all N taken up by the roots, whereas in later stages of development, the growth rates increased sufficiently for all N absorbed by the roots to be utilized for the production of more leaves.

The almost unlimited increase in leaf numbers at higher levels of N accumulation in shoots was associated with high availability of light and air space, as encountered in pot experiments.

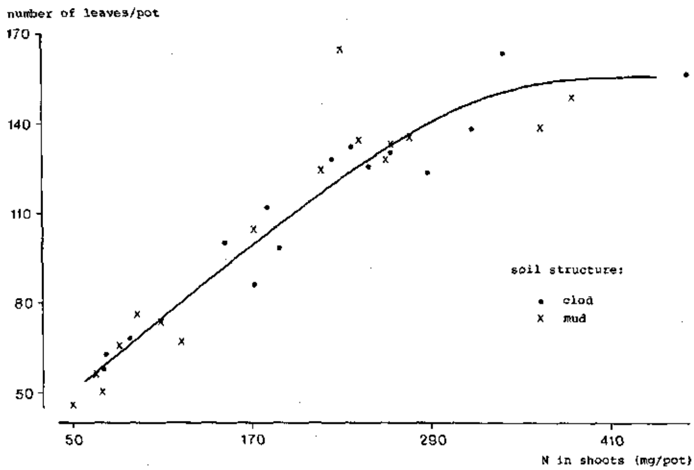


Figure 51. Relation between amount of nitrogen in shoots, and number of leaves per pot 55 days after sowing.

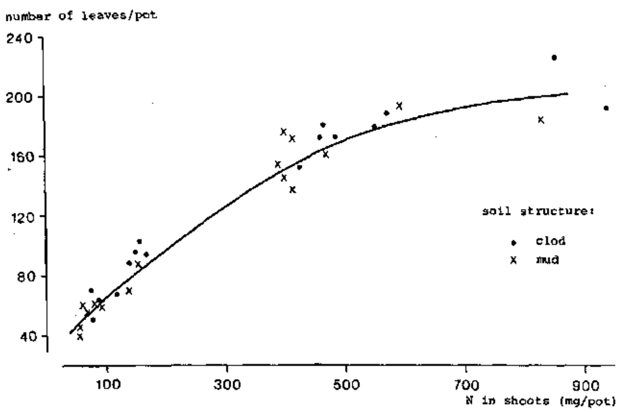


Figure 52. Relation between amount of nitrogen in shoot, and number of leaves per pot 72 days after sowing.

8.1.1.3 Preplanting N dressing (Pot Experiment 3)

This experiment is similar to Experiment 2, investigating the influence of previous soil drying on mineralization of nitrogen in soils under two structural conditions and on plant growth.

To compensate for the differences in available soil NH_4 resulting from drying to different levels, three amounts of urea were added (0, 192 and 384 mg N/pot) and incorporated in the soil before planting. All possible combinations of variations in drying level, soil structure and N application were present in the experiment. All pots received topdressings of 2 x 432 mg N/pot 45 and 74 days after sowing.

The levels of significance of the main effects of the treatments and of their interactions on a number of plants characteristics are presented in Table 49. For the shoot weights, the N contents of the shoots, and the yields

Table 49. *Fisher values* and levels of significance of the main treatment effects on plant characteristics measured at various days after sowing.

	Influence of								
	soil structure measured after			previous soil drying measured after			basal N dressing measured after		
	44 days	73	87	44 days	73	87	44 days	73	87
Characteristics:									
dry weight of shoots	1	2	5+	45++	33++	39++	8++	30++	14++
% N in shoots	8++	0	1	47++	4	2	23++	3	2
total N in shoots in mg (w/w) N/pot	3	6+	9++	78++	79++	44++	16++	59+	16++
Levels of significance:									
% K_2O in shoots at Day 44	++			++			+		
% CaO in shoots at Day 44				++					
% P_2O_5 in shoots at Day 44	++			++			++		
number of :									
leaves per pot at Day 44				++			++		
tillers per pot at Day 44				++			++		
tillers per pot at Day 72		+			++			+	
panicles per pot at Day 87									
% Ca in shoots at Day 87				++		++			
% P_2O_5 in shoots at Day 87									
NH_4 (mg/kg dry soil) before planting				++					

+ $0.05 > P > 0.01$; ++ $P < 0.01$; in all other cases, $P > 0.05$.

Table 50. Average values of characteristics showing significant effects (P <0.05) in Pot Experiment 3.

	Soil structure		Treatment					
	clods	mud	moisture content after previous soil drying			N applicated before planting, per pot		
			70%	40%	10%	0 mg	192 mg	304 mg
Harvest at Day 44:								
number of stems	36.8	35.6	32.1	33.3	43.4	31.6	37.9	39.2
number of leaves	144	139	126	129	169	124	147	153
dry weight of shoots (g/pot)			7.0	7.5	9.7	7.4	8.4	8.3
% N in shoots	3.12	2.84	2.42	2.89	3.62	2.65	2.83	3.45
% K_2O in shoots	2.56	2.73	2.35	2.73	2.85	2.56	2.62	2.75
% CaO in shoots	0.23	0.25						
% P_2O_5 in shoots	0.58	0.67	0.69	0.60	0.59	0.66	0.63	0.58
nitrogen yield (mg/pot)			174	218	346	206	244	288
total K_2O (mg/pot)	206	225	167	205	275	194	223	229
total CaO (mg/pot)			16.7	17.7	22.8			
total P_2O_5 (mg/pot)	45.9	53.7	48.0	44.4	56.7	47.9	52.8	48.4
Harvest at Day 73:								
number of stems	49.9	46.4	46.1	45.2	53.1	46.2	47.0	51.3
dry weight of shoots (g/pot)			26.5	27.6	34.2	25.0	30.8	32.5
% N in shoots						1.46	1.51	1.55
nitrogen yield (mg/pot)	456	431	385	415	530	374	451	505
Harvest at Day 87:								
dry weight of shoots (g/pot)	48.4	45.0	40.7	43.3	56.1	41.8	46.7	51.6
% CaO in shoots			0.43	0.45	0.41			
nitrogen yield (mg/pot)	732	672	629	644	834	639	692	776
total CaO (mg/pot)	211	190	176	193	232	180	195	226
total P_2O_5 (mg/pot)			164	160	216	161	183	196

of N per pot, the numerical F values are given. For the remaining plant characteristics, the number of asterisks indicates the level of significance.

For the three harvesting dates, the main effects of soil drying and of basal N dressings are highly significant except for the N content of shoots at the second and third harvesting. At the first harvesting, the effect of soil structure was noticeable only in the N content of the shoots. At the later harvesting dates, this effect manifested itself also in the dry weight of shoots and in the yield of N.

Other plant characteristics, except phosphate content of shoots, were all strongly influenced by soil drying. The basal N dressing affected most plant characteristics at the first harvesting, except CaO in shoots.

Summarized average values of the measurements that were significantly affected by the treatments are presented in Table 50. The positive influences of increased application of N before planting and of intensified drying of soil before planting, and the advantage of a clod structure over a mud structure appear to run parallel as can be judged from the data on number of tillers and leaves, dry weight of shoots, and yield of N. Phosphate in shoots runs counter to the general trend in some treatments. Decreases in phosphate content of shoots, with increasing N content were observed, whereas potassium contents increased along with N content. With improved N nutrition, the availability of phosphate may thus become the factor limiting growth. Under conditions of high N supply, K does not seem limiting.

The influence of soil structure on ammonium content of soil is given in Table 51.

The amount of NH_4-N in the soil was profoundly influenced by the intensity of drying before planting. The amounts of fertilizer nitrogen added to the pots before planting are one or two times the difference between maximum and minimum amounts of NH_4-N listed in Table 51. The amounts were 0, 192 and 384 g urea-N per pot.

As in Experiment 2, the amounts of nitrogen in the shoots 44 days after planting were related to the combined amounts of soil ammonium and fertilizer ammonium present per pot before planting (Fig. 53). Nitrogen added as urea was less efficient in raising the amount of N taken up by the rice plant than was nitrogen present in the soil as exchangeable ammonium at the start.

Without N applied before planting, N contents of shoots at 44 days were equal to or higher than NH_4-N in soil before planting. These results deviate from those in Experiment 2. This deviation will be due to the shorter period of flooding before planting (Exp. 2, 20 days; Exp. 3, 10 days), the longer

Table 51. Amounts of soil ammonium as influenced by physical treatment of the soil before planting

Previous soil drying	Clod structure	Mud structure
	mg NH_4/pot	mg NH_4/pot
70% moisture	124	143
40% moisture	168	175
10% moisture	288	329

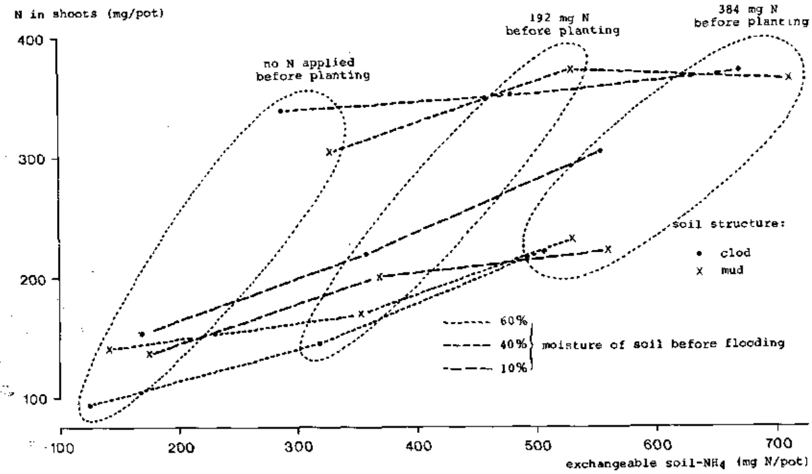


Figure 53. Relation between soil ammonium level at planting, basal nitrogen application, and amounts of nitrogen absorbed in the shoots of potted rice plants 44 days after sowing.

period of plant growth (44 against 34 days), and the use of another variety (Exp. 2, Acorni; Exp. 3, Awini). A larger amount of soil NH_4 before planting was accompanied by a higher utilization of soil N by plants at 44 days (nearly 100 %). The loss of N due to denitrification was therefore less and mineralization of soil organic N continued after planting at a higher rate than in Experiment 2.

At low initial levels of NH_4 in soil, the efficiency of the urea N added was around 33%; at high initial levels of soil NH_4, efficiency varied between zero and 20%.

All treatments received topdressings of urea 45 and 74 days after planting. A residual effect of the N initially applied, if present, can be estimated from the differences in N taken up by plants that had and had not received the basal dressing. Such differences are listed in the last column of Table 52. There was a negative residual effect when the rice plants grew on a soil with a clod structure that had not been dried before planting (70% moisture). With drying to 40% and 10% moisture, the residual effects were positive and increased with intensity of drying. The effect of drying is less pronounced for soil with a mud structure.

Of course, the estimates of the residual effects of the basal N dressing are likely to have been influenced by the production of soil NH_4 in the period covered, and by the topdressing at 44 days.

In plants that had not received basal dressing, the efficiency of the topdressing at 44 days was influenced by the intensification of soil drying

Table 52. Estimates of residual effects of a basal nitrogen dressing as calculated from amounts of nitrogen absorbed by rice plants in the period 44-73 days after planting. All values are in mg N/pot.

Previous soil drying to moisture %	Basal urea dressing	Dressing at Day 45	N uptake in period 44-73 days		Residual effect of basal dressing	
			clods	mud	clods	mud
70	0	432	233	188		
	192	432	227	230	- 6	42
	384	432	207	210	-26	22
40	0	432	146	226		
	192	432	218	210	72	-16
	384	432	195	264	49	36
10	0	432	96	144		
	192	432	249	245	153	54
	384	432	327	334	231	38

before planting, especially on soil with a clod structure. Variations in efficiency are presumably related to variations in shoot N at 44 days (Table 53). At this stage of growth, the plants developing on intensely dried soils had most N.

The total amounts of nitrogen in rice shoots at three different stages of development are presented in Table 53. At flowering, 87 days after planting, total N in plants growing on soil that had been dried to 10% moisture was 200 $\pm$ 20 mg per pot higher than in plants on undried soils (70% moisture); plants from soils dried to 40% moisture were intermediate. The advantage of clod structure over mud structure in raising the N uptake was highest in pots that had received no N before planting, and decreased with increasing level of N applied before planting. The effect of adding N before planting on the uptake of N by the rice plants was higher on the soil with a mud structure than on the clodded soil.

Of the three N-supplying factors investigated in this experiment, the average contributions of their extreme levels to shoot N contents at flowering are: previous soil drying, 200 mg N/pot; clod over mud structure, 50 mg N/pot; and preplanting N dressing, 140 mg N/pot.

The effect of previous soil drying on N contents of shoots at flowering was only present with most intense soil drying down to 10% moisture. The increase in drying intensity from 70% down to 40% moisture has no effect on N contents of shoots at flowering. These patterns accord with data on extractable

Table 53. Effect of soil treatments and two nitrogen dressings* on uptake of nitrogen from soil and fertilizer by rice plants in different growth periods.

Previous soil drying moisture %	Basal dressing (mg N/pot)	Total N in shoots (mg/pot)					
		Day 44		Day 73		Day 87	
		clods	mud	clods	mud	clods	mud
70	0	97	140	330	328	584	505
40	0	152	134	298	360	656	540
10	0	344	303	440	447	805	725
70	192	148	167	375	397	650	605
40	192	219	200	437	410	650	580
10	192	351	367	600	565	825	810
70	384	223	230	430	440	720	685
40	384	302	224	497	488	716	718
10	384	262	365	695	574	920	878

* All pots received two topdressings of 432 mg N/pot at 45 and at 74 days after sowing.

soil ammonia before planting and the findings in Pot Experiment 2.

The effect of soil structure of N contents at flowering was dependent on the level of basal N dressing. The greater content of N in shoots with clods than with mud decreased with increasing fertilizer N applied before. The average contributions of clod against mud structure for 0, 182 and 384 mg N/pot preplanting N dressing were 80, 40 and 25 mg N/pot, respectively.

The effect of N applied before planting on N contents of shoots at the active tillering stage (44 days) amounted to 30% of the applied amount of fertilizer (Fig. 53). The recovery of the fertilizer N at flowering was relatively low at a low level of N dressing and varied with soil structure. With clods, the average recoveries at the low and the high level of N dressing were 12 and 28%, respectively; with mud, the recoveries were 20 and 45%, respectively.

The contribution of previous soil drying to shoot N contents at flowering was independent of soil structure and of basal N dressing. The increases in N accumulated in shoots (200 mg N/pot) were identical for both soil structures. This amount is of the same order as the increases in extractable ammonium before planting, which amounted to 160 and 185 mg N/pot for clod and mud structure, respectively. As the period before flooding was only 10 days, mineralization is assumed to have continued after planting. At 44 days after seeding about all the soil ammonium extractable before planting was recovered in shoots. At this stage, plants on clods yielded less shoot N than those on mud soil. The rice plants on clods absorbed more nitrogen thereafter, amounting to 80 mg N/pot in the absence of N applied before planting. This larger absorption may be due to a larger supply of soil ammonium through mineralization, or through a higher efficiency of the N applied 45 and 74 days after sowing. In Experiment 2, the recovery of fertilizer N in pot trials was the same for the two dressings combined with mud or clod structure. Hence, more mineralization of organic N after 44 days had taken place with clods. The contribution of this clod-structure effect to N accumulation in shoots up to flowering decreased with increasing amount of fertilizer N applied before planting.

8.1.2 Field trial

In general, heavy puddling after dry plowing is not practiced. Dry plowing or puddling, sometimes combined with seedbed treatment, is considered adequate for growth of rice. Puddling in addition to dry plowing seems a waste of effort. In some field trials, the effects of soil conditions in the pot experiment were compared with the same effects in the field. The results of the field trials are limited to grain yields (Table 54). Further details of the trial are given in Section 11.1.2.

Mudroll treatment twice is considered an extreme puddling treatment. It is not practical in normal culture. The other treatments are normal practice. Puddling intensity in seedbed preparation increases in the order given in Table 54. This increasing puddling intensity results in decreasing yields.

In other field trials, after dry plowing and drying of the soil down to 10% moisture, a clod and a mud structure were established: the first with a beam on a dry field; the second with a stalkcutter and a mudroll on a flooded

Table 54. Effect of increased puddling intensity during seedbed preparation after dry plowing on grain yield of rice.

Tillage treatment	Yield in kg/ha	Differences in yield from 1st treatment (kg/ha)
dry plowing twice + wooden beam on dry soil	4650	
dry plowing twice + wooden beam on flooded soil	4350	-300
dry plowing twice + mudroll once on flooded soil	4300	-350
dry plowing twice + mudroll twice on flooded soil	4150	-500

Table 55. Response of three rice varieties to heavy puddling after dry plowing.

Tillage	Maximum grain yield (kg/ha)		
	Apura	Awini	Acorni
dry plowing twice + wooden beam on dry soil	5250	4375	5000
dry plowing + mudroll thrice on flooded soil	5025	4250	4725

soil. In three trials, three rice varieties were used, namely Apura, Acorni and Awini. Thus, the response of these varieties to differences in soil structure could be examined. All these trials included two levels of urea (120 and 180 kg per ha), in split dressings. With the variety Apura, the same amounts were split into 4 portions, with Acorni and Awini into 3 portions. The times of application were associated with stages in the development of the rice. The summarized results are presented in Table 55. Further details will be presented in Section 10.3.

For the various soil tillage treatments, maximum yields were obtained with different amounts of fertilizer and with different distributions of the fertilizer over the growth stages (Chapter 10).

For all these varieties, yields were depressed by intense puddling after dry plowing. These results accord with those of the pot experiments (8.1.1). The differences in yield between the three varieties are caused by factors other than soil tillage.

8.2 PLANT DENSITY

For a plant that forms many tillers, like rice, the number of plants per unit surface of land is an important factor in determining growth and grain yield. Due to mutual shading, plant density influences the relative rate of photosynthesis to respiration, which in turn governs grain production.

Plant density is governed by the number of seeds per unit area and by seedling establishment. In a pot experiment, plant density can be controlled by planting a fixed number of plants per pot. In field trials, seed establishment cannot easily be controlled, since there are differences in seedbed conditions resulting from variations in tillage treatments and uncontrollable conditions such as weather.

Seed establishment as a function of tillage treatment was studied (8.2.1). The effects of seed rate and N dressing on plant density and vegetative growth were investigated in section 8.2.2.

8.2.1 Seedling establishment

Factors like seed quality, pretreatment of the seed, soil, weather and damage by animals all influence the proportion of pre-soaked seeds that become established. The influence of the type of seedbed on the rate of seedling establishment depends on weather. The influence is most noticeable, when evapotranspiration is high.

Shortly after sowing pre-soaked seeds, the field are drained (1.5.3). In this period, the newly emerged root of the seedling needs contact with easily available water. Such water is always present in the surface layer of puddled seedbed. Roots can extend easily into the muddy topsoil (Figures 54 and 55). But with high evaporation, the surface layer may dry to a crust and may crack intensely (Figure 56). When root penetration keeps ahead of the drying zone, the roots have a certain supply of available water. Only in extreme situations will flooding be needed, but not until the roots have penetrated into the soil.

When the seedbed consists of soil with a clod structure, water is not equally available throughout the seedbed. The space between the clods is partially filled with free water. With high evaporation, the upper parts of the clods dry out quickly. Pre-soaked seeds on such clods die from lack of water. Surface portions of the clods that are less far removed from the puddles of water between the clods remain moist due to capillary movement of water. Seeds that fall on the upper part of clods commonly fail and seedlings establish normally on the lower parts of the clods (Fig. 57). Seedling establishment is usually poor in the small puddles between the clods that are often covered with a violet-blue film of material that presumably consists of iron hydroxide.

When the seedbed is covered with stubble or other plant debris, seedling establishment is usually poor. The layer of stubble and plant debris dries out quickly, since water is not replenished by capillary movement. Seedling roots dry out before they even reach the soil surface.

When evaporation is high, a zero-tilled surface can be disastrous for seedling establishment. The layer of partly burned plant debris is relatively thick since this material is not mixed with the topsoil. This plant debris dries out quickly, because of the low capillary rise due to the limited contact

Figure 54. Puddled seedbed after wet tillage with stiffening of sedimented layer, due to surface drainage after sowing, and with slight cracking. The seeds fall and penetrate the mud and are therefore not visible.

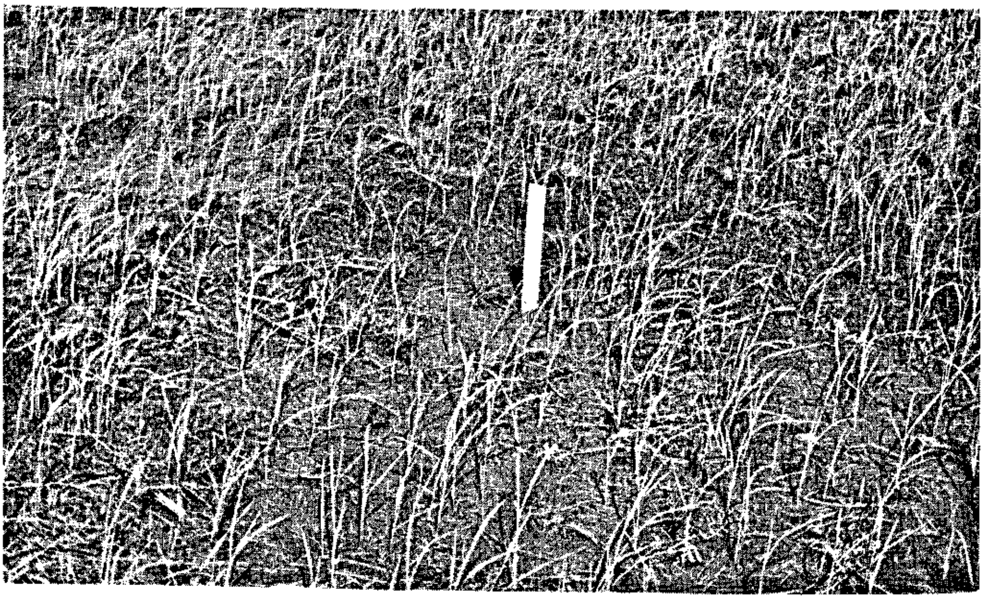


Figure 55. Puddled seedbed after dry/wet tillage with the surface smoothed by the wet seedbed preparation, but some unevenness from clods is still visible.

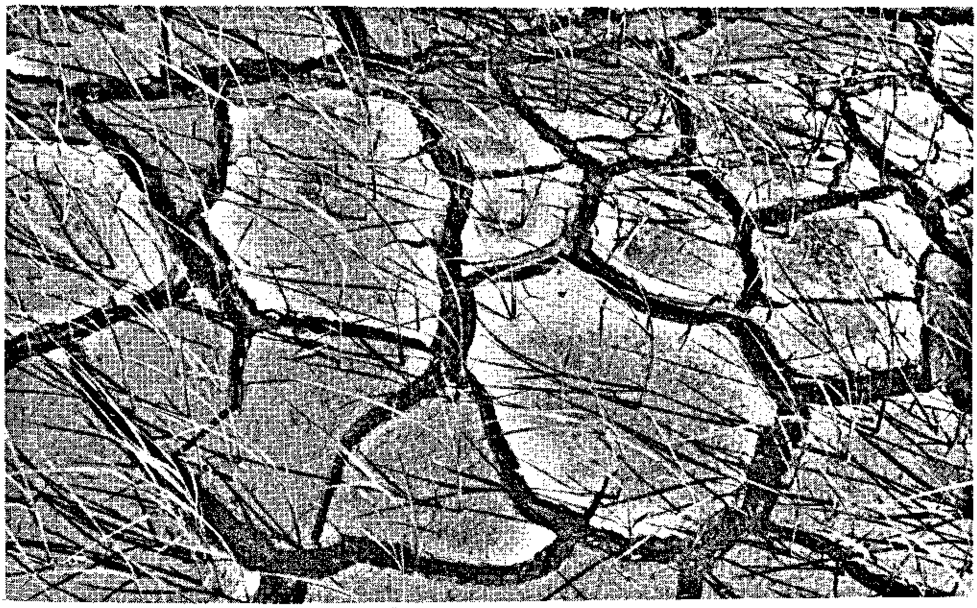


Figure 56. Intensely cracked puddled seedbed after wet tillage and a surface-drainage period with drying weather and no rain.

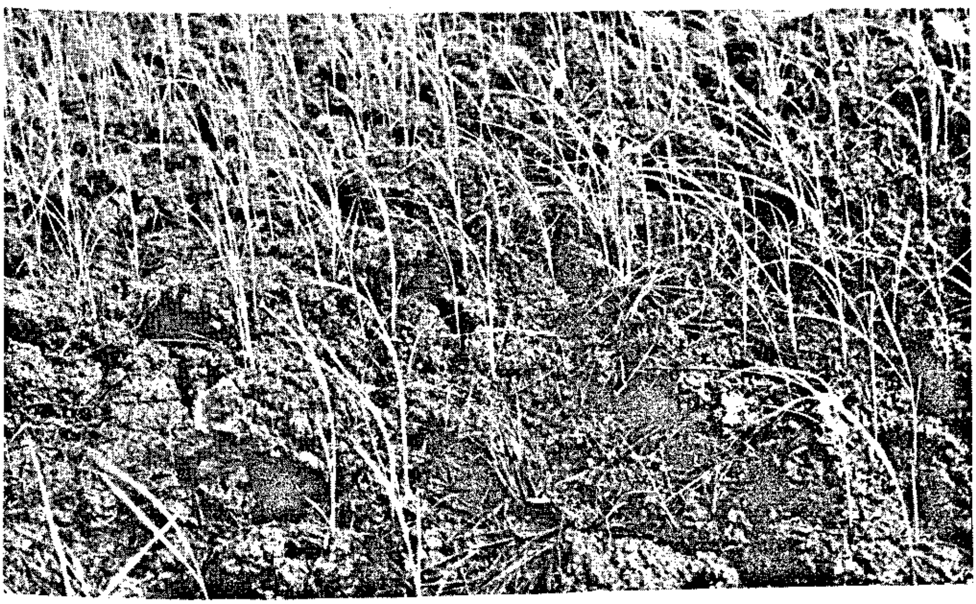


Figure 57. Unpuddled seedbed after dry tillage. Large clods and stubble remain on the surface, and small pools of water hinder seedling establishment here and there.

between the layer of debris and the soil. Moreover the top layer of the soil is slightly compacted (6.2) and hardened by drying in the intercrop period.

Through lack of free water in puddles, the rise of capillary water is less than in a soil with a clod surface. Furthermore, the water-holding capacity of a soil under zero-tillage is less than that of a soil with puddled topsoil.

Seedling establishment was studied during three cropping seasons: the autumn of 1969 and the spring of 1970 and 1971. The first two seasons were the second and third seasons of three successive seasons in which the same tillage treatments were applied in the same places. In all three seasons, the variety used was Apura. The seed rate was 90 kg/ha. Seedling establishment as a function of soil tillage and of weather was evaluated by counting the number of established seedlings in each of 20 plots 0.25 m^2 in area for each treatment. The average results are presented in Table 56.

In autumn 1970, the weather after sowing was extremely sunny. The peaty mat of organic matter, resulting from three consecutive seasons of zero tillage, prevented proper contact between seedling roots and soil water and caused most of the seedlings to die. Puddling as a tillage treatment increased seedling establishment. There were no differences between dry/wet and wet tillage. Dry tillage produced 10-20% less seedling establishment than did tillage treatments including puddling. Differences in weather after sowing affect seedling establishment more after zero tillage than after other tillage treatments. With zero tillage, seedling establishment ranged from almost zero to values approaching those with puddling.

In another experiment (Table 57), the number of tillage operations to form a puddled layer and a seedbed were varied. Four subtrials were arranged. Three

Table 56. Seedling establishment as influenced by tillage in three growing seasons (var. Apura). For relative establishment, the tillage treatment giving the most plants in each season was taken as 100.

Tillage	Number* of plants in ¼ m^2 plots			Relative number of plants		
	1969 autumn	1970 summer	1971 summer	1969 autumn	1970 summer	1971 summer
wet	53	53	60	100	91	100
dry/wet	50	58	59	94	100	98
dry	41	55	49	77	94	81
zero	48	5	47	90	8	78

* mean values of 20 counts at a seedrate of 90 kg/ha.

Table 57. Effect of tillage operations on seedling establishment.

Number of plants	Preparation of tilled layer							Seedbed preparation			
	subtrial 1		2		3			4			
	weedcutter		stalkcutter		plowing			wooden beam		mudroll	
	2x	4x	2x	4x	1x	2x	3x	dry 1x	wet 1x	1x	2x
per ¼ m^2	51	46	61	45	45	47	45	41	43	48	44
relative number	100	90	100	73	95	100	95	85	89	100	91

included tilled-layer preparation, one with the weedcutter, another with the stalkcutter for puddling, the third with an offset-disc-plowing harrow. The fourth subtrial included seedbed preparation after dry plowing with a beam or a mudroll as implements. The season of the trial was the not extremely sunny spring of 1971.

Increasing the number of operations to form a tilled layer in flooded fields tended to decrease seedling establishment. For the stalkcutter, this decrease was significant (5%). No influence on seed establishment was noticed by increasing the number of plowing operations in Subtrial 3. The intensity of seedbed preparation increases in the order listed in Table 57. Seedling establishment tended to be better with mudroll treatment than with a wooden-beam treatment.

8.2.2 Seeding rate and nitrogen dressing

Plant density is determined by seedling establishment. Subsequently, vegetative growth of the plants will produce a canopy. Seedling establishment was shown in 8.2.1 to be dependent on seedbed conditions. Vegetative growth is largely determined by the ability of the soil to provide the growing plants with nitrogen. N nutrition of rice is tillage-dependent, and is regulated by N fertilizer application (7.1; 8.1).

In a factorial experiment (Field Trial 1), the effects of seed rate and amount of N fertilizer on certain plant characteristics, and on grain production for the four tillage treatments were investigated. The nitrogen was applied as urea in three equal split dressings 35, 60 and 85 days after sowing.

These days corresponded with active tillering, panicle initiation, and panicle differentiation, respectively. For detailed information about Field Trial 1, see 3.3.

Seedling establishment

The effect of seed rate of variety Apura on seedling establishment at the various soil tillage treatments is shown in Table 58. The data represent averages of results obtained on 20 plots 0.25 m^2 in area for each treatment. Nitrogen was first applied 35 days after sowing and therefore does not influence the data in that table.

Within tillage treatments, seedling establishment tended to decrease with increasing seed rate. Tillage treatments including puddling proved favourable for seedling establishment.

Seedling growth

The way in which plant growth was influenced by seed rate was also investigated (Table 59).

Table 58. Effect of seed rate on seedling establishment.

Tillage	Number of plants per ¼ m^2				Percentages of surviving seedlings				Survival as a % of highest percentage surviving seedlings for each seed rate			
	30	60	90	120 kg/ha	30	60	90	120 kg/ha	30	60	90	120 kg/ha
Wet	21	43	53	74	88	88	77	75	84	100	100	100
Dry/wet	25	38	50	63	(104)	77	70	59	100	88	94	85
Dry	19	28	41	47	(80)	58	55	50	95	81	90	70
Zero	20	35	48	52	75	72	67	54	76	65	77	63

Variety Apura; averages of 20 countings.
Bracketed values: counting frames moved because there were too few seedlings.

Table 59. Effect of seed rate on plant parameters of seedlings 30 days old.

Tillage	Shoot weight (g/m^2)				N accumulated in shoots (kg/ha)				N in shoots (% w/w)			
	30	60	90	120 kg/ha	30	60	90	120 kg/ha	30	60	90	120 kg/ha
Wet	41	62	66	77	12	17	19	21	3.0	2.7	2.9	2.9
Dry/wet	39	53	71	76	12	14	19	21	3.2	2.6	2.7	2.7
Dry	26	29	41	42	8	9	13	12	3.0	3.2	3.1	2.9
Zero	25	34	43	53	7	10	12	17	2.9	3.0	2.7	3.2

With differences in seedling establishment, growth with dry and zero tillage started with fewer plants than with dry/wet and wet tillage. Besides this initial handicap, growth with the former two tillage treatments fell behind even further for dry weight of shoots after 30 days of growth. The retardation in growth cannot be ascribed to nitrogen deficiency, as can be judged from the data on N content of the shoots.

The actual cause is likely to be a lack of available water during the first few days after emergence. With dry tillage and zero tillage, the plants took some days to recover from this setback. Normally, before panicle initiation, the dry weight of plants on dry-tilled soil surpasses that of plants on wet-tilled and zero-tilled soil. Plants growing on dry/wet-tilled soil tended to be heavier than those on dry-tilled soil throughout the growing period, although they yielded less grain.

Plant development

Grain production in rice culture is dependent on a number of factors. The first, seedlirg establishment, has already been discussed. The established seedlings develop tillers. Tillering is the second factor on which grain production depends. Tillers may or may not develop panicles. Thus, grain production is not only dependent on tillering, but equally on the ability of tillers to produce panicles. Other factors on which grain yield depends are the number of grain per panicle and the weight per grain.

Since maximum number of grains per panicle is genetically determined, the number of productive tillers per unit area will be an important factor in grain yield.

Grain yield will rise along with an increase in number of tillers. The optimum number of tillers is reached when maximum grain yield is obtained. With a further increase in number of tillers, grain yield will decline, through an increase in the number of unproductive tillers. Excessive mutual shading lowers the photosynthesis respiration rate and decreases net carbohydrate production.

For the four extreme combinations of seed rate and N dressing, the development of the rice crop from seed to panicle is presented in the Figure 58. A low seeding rate of 30 kg/ha resulted in large differences in crop development between the tillage treatments. At high seed rate and low N dressing, the differences were smaller; at high seed rate and high N dressing, the difference almost disappeared.

In general, tillering was low with zero tillage, increasing in the order of dry, wet and dry/wet tillage. Only with both the high rate and high N

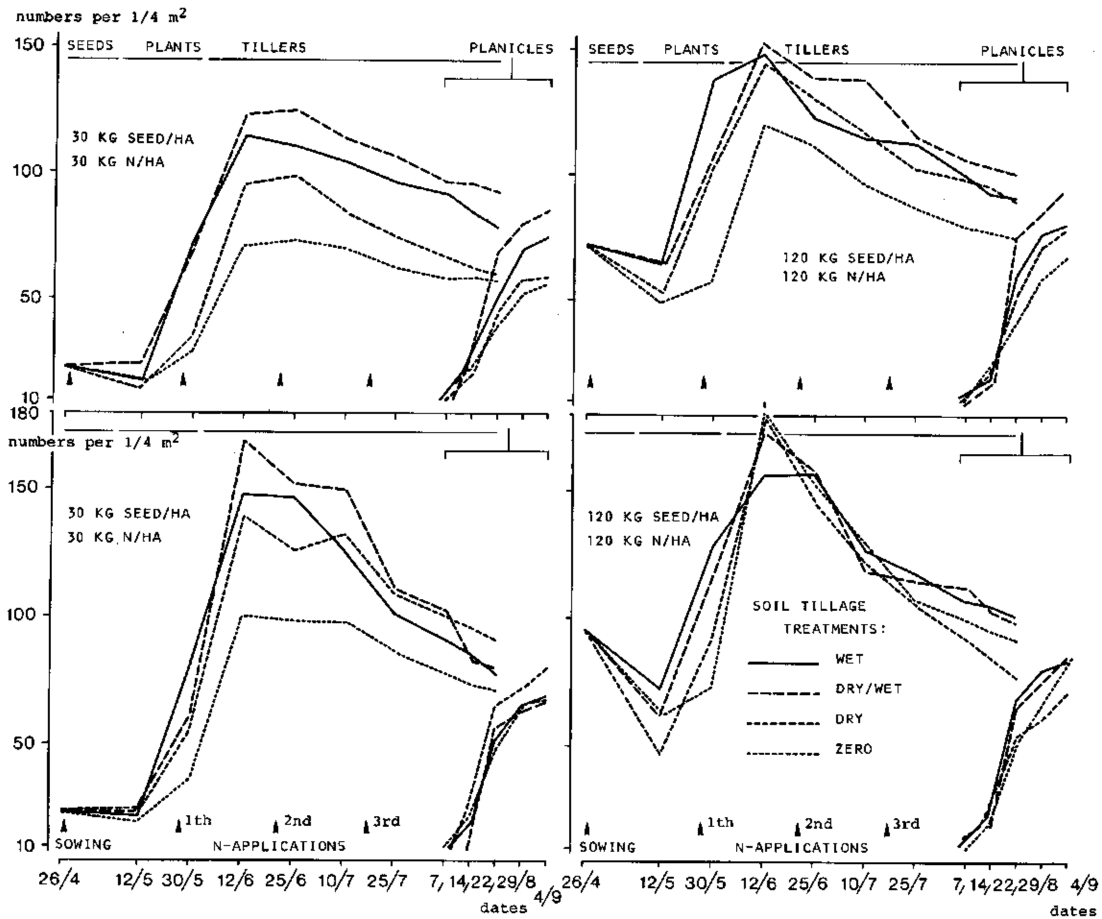


Figure 58. Effect of seed rate and nitrogen application on number of plants, tillers and panicles, after different tillage treatments.

dressing was this order reversed. The number of tillers varied from 75 to 185 per 0.25 m^2. The efficiency of tillering, expressed as the percentage of tillers producing a panicle, ranged from 30% to 90%. High levels of N resulted in a low efficiency; low seed rates resulted in a high efficiency. At a seed rate of 120 kg/ha, the panicle/plant quotient was about 1; at a seed rate of 30 kg/ha, this quotient was 2-3.

With the low N rate, panicle formation decreased with tillage treatment in the order dry/wet, wet, dry and zero tillage. At the high rate, the differences were less pronounced. Dry tillage induced a higher level of panicle formation at the low seed rate, and a lower level at the high seed rate.

Grain yield

The link between panicle production and grain yield is grain production per panicle. Grain production per panicle depends on the number of grains per panicle and the average grain weight. A lower panicle production may give rise to a higher total grain yield. Such a situation was encountered with the combination of the high seed rate and the high N dressing. Figure 58 shows that panicle production was higher on the plot with dry/wet tillage than with dry tillage. Figure 59 shows that grain yield was higher after dry tillage than after dry/wet tillage.

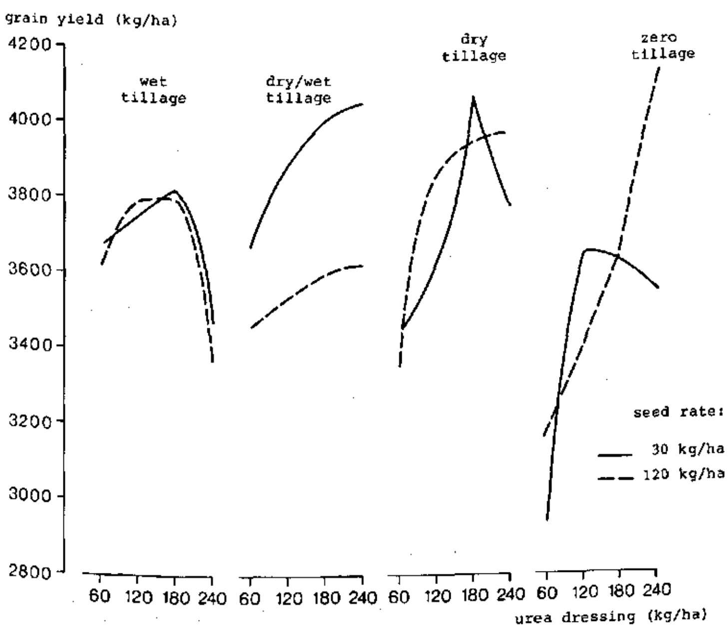


Figure 59. Effect of seedrate and nitrogen application on grain yield after different tillage treatments.

Figure 59 shows the relationship between grain yield and N fertilizer level for the two extreme seed rates. At the high seed rate, there was no effect or a negative effect of N fertilizer for wet and dry/wet tillage. At the low seed rate, N fertilizer increased grain yield in all tillage treatments, except the wet treatment.

Grain yield on dry-tilled and zero-tilled soil increased with N fertilizer at high seed rates. At low seed rates, however, high levels of fertilizer were not effective. Grain yield on the dry/wet tilled soil decreased with the high seed rate. At this treatment, the response to high levels of N was zero at the high seed rate, and positive for the low seed rate. With wet tillage, grain yield was not affected by differences in seed rate, and by variations in N fertilizer except that at the highest fertilizer rate, yield was lower.

The response of rice to N fertilizer with dry tillage and zero tillage indicates that nitrogen was there the factor most influencing yield, provided a sufficient plant density was reached. Because of the lower seedling establishment and slower seedling growth, high rates of N at the high seed rate still did not cause excessive mutual shading. The low rate of N mineralization with zero tillage increased the need for high N rates at high seed rates. The N is applied at a late stage of tillering, so that the effect of it on tiller formation remained limited, hence an absence of crop response to fertilizer N for the combination low seed rate and high N rate. On wet-tilled soil, the response of rice to variations in seed rate and N level was practically absent. For this tillage treatment, ensuring a good seedling establishment, plant density was not a limiting factor. Absence of a positive response to N fertilizer, even though the mineralization of soil organic nitrogen was found to be low, suggests that other factors limited yield for wet tillage.

The negative response of rice with dry/wet tillage to high seed rates may have been caused by excessive mutual shading. Seedling establishment and mineralization of soil organic nitrogen was high. Under such conditions, a low seed rate and a moderate rate of N ensure high grain production.

Large numbers of tillers with many thick leaves lead to an ineffective use of photosynthesis and cause large amounts of nutrients to be locked up in unproductive or dying plant tissue. Such a locking up may be particularly harmful during panicle differentiation when utilization of nitrogen by the rice plant determines the number of spikelets.

8.3 ROOTING HABITS

To evaluate different physical conditions of soil in terms of plant-root environment, rooting habits of rice in soils that had received the four different tillage treatments were studied.

The study was largely unsuccessful. Roots could not be distinguished in healthy, weakened or dead, partially because of difficulties encountered in separating roots without breakage from the heavy clay soil.

The extremes in appearance of the roots were fresh white or shiny brown roots and totally decayed dull gray-brown flat roots. The description of the rooting habits is limited to some general remarks on observations made, irrespective of the tillage treatments used.

Two main stages of root development could be distinguished. The first extends up to the period when the internodes of the stems start to lengthen, the roots extending downwards in a cone-like arrangement. The roots penetrate relatively deeply into the soil, with lower boundaries down to 50 cm. The majority of the root system is in the upper 30 cm. Many roots penetrate the soil underlying the tilled layer.

The second stage of root development starts at stem elongation. The newly formed roots develop more horizontally. They tend to form a root mat in the upper few centimetres of the tilled layer and on the soil surface. These roots are thinner and more heavily ramified than the earlier roots. Roots also develop from nodes on the submerged portions of stems. Their appearance resemble the roots of the root mat.

The formation of this root system is associated with the lengthening of the pathway along which oxygen has to travel from the leaves through the stems to the roots. For their oxygen requirements, roots present on the surface and in the top few millimetres of aerated soil are independent of oxygen diffusion through the rice plant to the roots.

Old roots formed during the first stage are still present. Their activity could, however, not be established.

Apart from these two stages of root development, two special features can be noticed. They are (1) black bands forming around the root cylinder, and (2) accelerated development of new roots after surface drainage for 4 days.
(1). Black band, some centimetres from the proximal end of the roots (Figure 60). When these bands or rings occur, almost all roots display them at the same depth below the soil surface. The width of the band is usually a few millimetres. The intensity of the black colour varies.

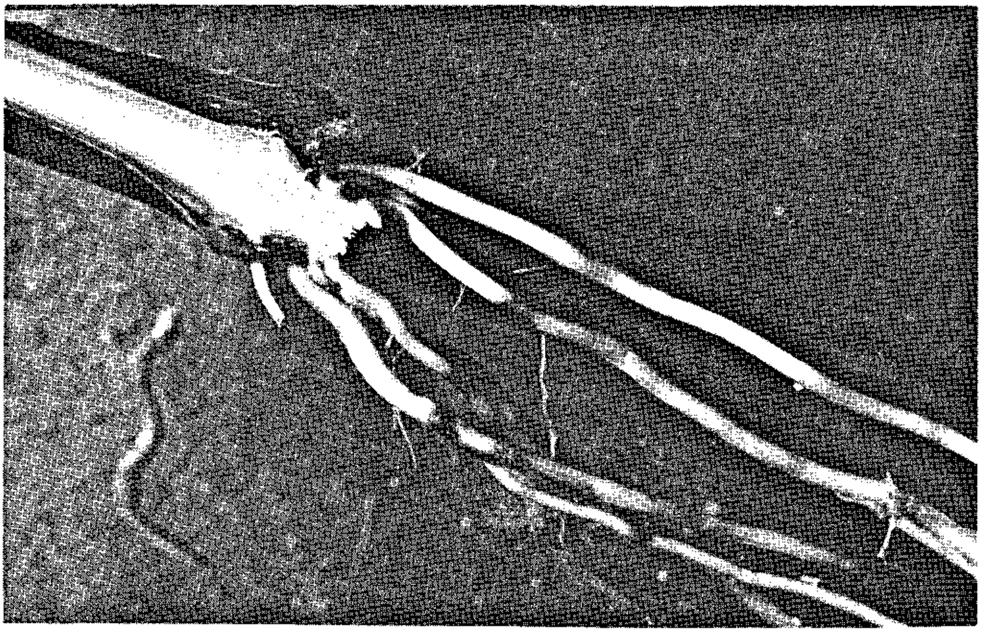


Figure 60. Black bands occurring on rice roots.

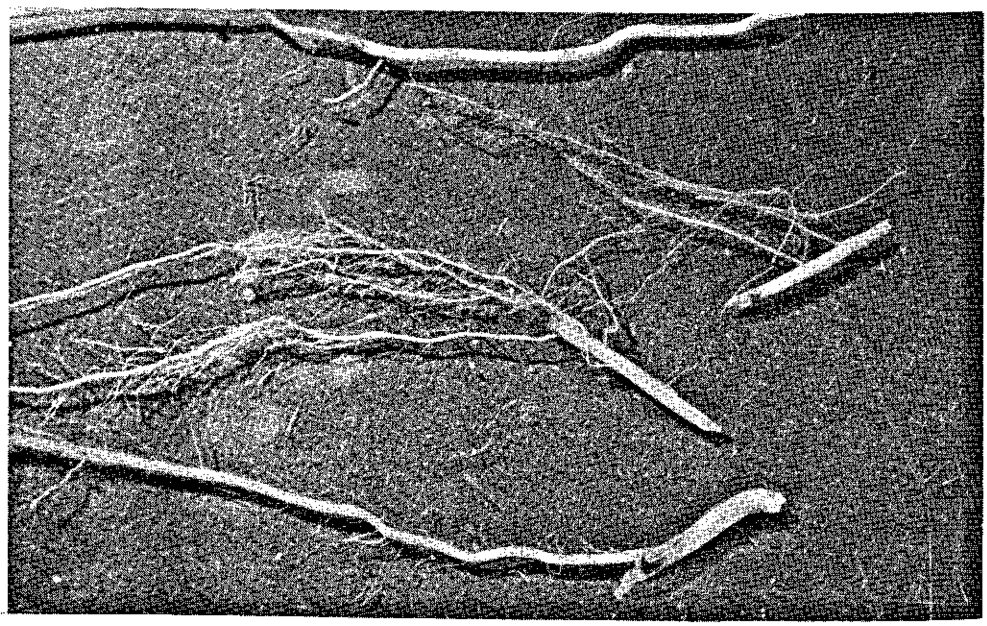


Figure 61. New secondary roots develop just proximal to the black bands, distal to which the root is decayed.

No consistent relationship could be established between the occurrence of such bands and the type of tillage, the age of the plant or any other factor. Sometimes, two or more bands occur one above the other, with one or more centimetres between them. The black colour changes to light brown, when the bands are exposed to air. Because of this colour change the bands are supposed to be formed by iron sulphide. At the band, the root is slightly constricted.

Distal to the band, roots vary in appearance from fresh and healthy to totally decayed. If the proximal portion of the root is decayed, a sharp boundary in root appearance is noticeable just at the black band. Hence, root decay may be related to the black band. Sometimes new lateral roots are formed just proximal to the black band (Figure 61).

The presence of insoluble iron sulphide in the root environment is not necessarily harmful to root. The sulphide ion, however, is known to be toxic to roots. No data are available on the occurrence of sulphide ions in rice soil in the Wageningen Polder.

(2). Accelerated formation of new roots. After a surface-drainage period, accelerated development of new roots can often be noticed, with and without urea being applied during drainage. The type of soil tillage had no influence on this feature.

SUMMARY CHAPTER 8

1. In pot experiments the effects of soil drying before flooding (70%, 40%, 10% moisture) of soil structure (clods, mud), and of N fertilizer on the growth of rice were studied.

   Dry matter production was influenced throughout the growing season by the degree of previous soil drying and after tillering also by topdressing and by soil structure. Intense soil drying (10% moisture) and clod structure and the application of fertilizer N after tillering affected dry matter production favourably.

   N accumulation in the rice plant up to tillering (i.e. before N dressing) was promoted greatly by intense soil drying, and to a lesser extent by a mud structure in comparison with a clod structure. High percentages (70-100%) of soil ammonium present in the soil at the time of sowing were recovered by the rice plants at tillering. In the absence of N fertilizer, little additional soil ammonium was absorbed by the rice plants after tillering.

In the absence of intense soil drying prior to flooding, the lack of available soil ammonium could be compensated with a N dressing before sowing. About a third of such a basal N dressing was recovered by the plants at tillering.

Recovery of fertilizer N applied as topdressing after tillering was highest after intense soil drying (45-72%) and increased (from 42 to 66%) with advance in the growing season.

At flowering, N accumulation in rice plants was stimulated most by topdressings at tillering and panicle initiation (by a factor of 5), less by intense previous soil drying (by a factor of 1.7) and least by type of structure (clod structure over mud structure by a factor of 1.1).

2. In field trials, soil tillage proved to be an important factor in affecting growth of the rice plant up to tillering.

   Seedling establishment on the drained surface was influenced strongly by the availability of water to the emerged seeds. In a puddled seedbed with dry/wet and wet tillage, water is highly available and there is no risk of desiccation of young seedlings. In drying weather, the emerged seedlings on top of clods (dry tillage) and on the untilled surface (zero tillage) may die through shortage of water.

   Seedling growth during surface drainage was regulated by the availability of water to the seedlings, the growth decreased in the order dry/wet, wet, dry, zero tillage. With dry tillage, the original setback due to low water availability was not completely offset by increased N availability until the tillering stage:

   Nitrogen contents in the shoots increased in the order zero, wet, dry/wet and dry tillage. This sequence agrees with the one found for the levels of soil ammonium.

   Accumulation of N in shoots, being a function of both dry matter production and nitrogen content of the dry matter, was found to increase in the order zero, dry, wet, and dry/wet. The rate of tillering increased in the same order.

3. Type of tillage, seed rate and fertilizer nitrogen all influenced crop density, number of tillers produced per panicle and, hence, grain yield. Both an excessive number and an insufficient number of tillers proved to reduce grain yield. Low tillering limits the number of panicles and thus the number of grains formed. An excessive number of tillers caused excessive mutual shading and an unfavourable assimilation-dissimilation ratio, a high percentage of barren tillers, and, hence, in low kernel numbers and kernel

weights.

At both extremes of the influence of soil tillage on seedling growth, seed rate influences grain yields. With zero tillage, a low seeding rate reduced the number of plants and hence the number of tillers per unit area; causing high rates of fertilizer to be ineffective. Higher seeding rates increased yields and enabled the crop to respond favourable to high levels of fertilizer N. With dry/wet tillage, tillering was excessive and led to heavy mutual shading. High seed rates lowered grain yields and caused N fertilizer to be ineffective. Lower seed rates enabled the crop to respond favourable to fertilizer N.

With the tillage treatments giving intermediate seedling growth (dry and wet), seed rate has little effect on grain yield. With dry tillage, the crop responded favourably to fertilizer N. With wet tillage, moderate rates of fertilizer raised yield only slightly, whereas high rates depressed yields.

4. Root development was not affected by variations in tillage.

With all tillage treatments, black rings occasionally appeared around roots a few centimetres below the soil surface. The black colour was probably caused by precipitation of ferrous sulphide. Distal to the black ring, roots often died, while just proximal to the rings new laterals formed. Often, however, roots were found to be white, thick, and healthy.

Independent of the level of N fertilizer, a period of surface drainage appeared to stimulate the formation of new crown roots.

9 Aspects of nitrogen fertilizer

Plant growth is influenced directly by soil tillage (Chapter 8). Seedling establishment and -growth and crop growth were found to be related to type of tillage. The influence exerted by soil tillage on the rate of mineralization of organic nitrogen in soil was an important factor in the response of the rice plant to variations in tillage.

Besides soil nitrogen, fertilizer nitrogen exerts an influence on plant growth and grain yield. Interactions between fertilizer nitrogen and tillage were also found. In Chapter 10, the effects of fertilizer N on grain yield will be discussed. Attention will now be paid to the influence of fertilizer nitrogen on N accumulation in aerial parts (9.1) and on soil ammonium (9.2). The main variety used was Apura.

The recovery of fertilizer N was evaluated in terms of amount of N withdrawn by the crop. It was estimated at various stages of shoot development for the four tillage treatments.

The fate of the N applied as urea was partly investigated (9.2). This investigation was restricted to comparisons of soil ammonium before and after N dressing. N fertilizer was applied in various ways. The different methods were related to the variations in water management.

9.1 ACCUMULATION OF NITROGEN IN SHOOTS

Grain yield of rice is strongly influenced by the availability of nitrogen. Many field trials have shown that nitrogen nutrition of rice is the most important factor in yield. Nitrogen nutrition is affected by the type of soil tillage. Section 8.1.1 showed that in pot experiments availability of soil nitrogen depended on soil structure and on degree of soil drying before flooding. Differences in nitrogen availability caused by variations in tillage treatment could be compensated for by application of fertilizer nitrogen early in the growing season. Field trials (ten Have, 1967) showed that incorporation of fertilizer nitrogen into the soil before sowing did not promote grain yield. Only split dressings of nitrogen during the growing season were effective.

Section 9.1 presents the effect of N fertilizer on accumulation of N in rice shoots in the field (Field Trial 7).

9.1.1 Tillage

The first dressing was at active tillering so that there could be no response to fertilizer at earlier stages of growth.

The N accumulated in tillers at active tillering as influenced by soil tillage treatment will be dealt with.

Subsequently, at the stages of active tillering, panicle initiation, panicle differentiation and flowering, respectively, the effects of split applications of N on the N accumulated in the shoots of rice are examined.

Data on yield of N in shoots at active tillering, before any fertilizer N was applied, are presented in Table 60. The data apply to soil tillage trials in both spring (S) and autumn (A). The age of the rice plants at sampling was 30-35 days.

The amount of N accumulated in shoots varied widely, depending on season and soil tillage. The accumulation of plant N at active tillering was determined by dry-matter production per unit area and by the N content in dry matter. The yield of dry matter per unit area is a function of seedling establishment and of growth rate of the seedling. For dry and zero tillage both characteristics are determined by availability of water and by the weather after sowing. The influences of soil tillage on seedling establishment were dealt with in Section 8.2.1. Established seedlings did not all grow at the same rate. Any differences tended to decrease when the fields were flooded about 14 days after sowing but the differences were still noticeable when 30-day old plants were sampled.

Table 60. Nitrogen accumulated in shoots up to active tillering, as influenced by tillage in three growing seasons.

Tillage	N (kg/ha)				
	1969-A	1969-S	1970-A	1971-A	1971-A
wet	20	19	21	11	17
dry/wet	21	19	33	21	24
dry	21	13	18	30	18
zero	16	12	')	15	12

')not determined through crop failure.

For wet and dry/wet tillage, chemical reduction of soil constituents may retard seedling growth. In those tillage treatments, the incorporation of fresh organic matter into the soil was most intense. Reduction is accelerated by the presence of fresh organic substrates. In addition, because of restricted mobility of solutes, harmful concentrations of reduction products may arise in the soil solutions.

N percentage of shoots is related to the availability of soil nitrogen. Depending on weather, differences in N availability between soils treated differently varied from field to field. Usually at active tillering N contents after dry and zero tillage exceeded those after wet and dry/wet tillage. The lower production of dry matter after dry and zero tillage caused accumulation of N not to exceed that after wet and dry/wet tillage.

At active tillering, yields of N were generally low after dry and zero tillage. In the 1970-A season, seedlings on the zero-tilled plots almost all failed to establish themselves and these plots were not sampled. The highest yields of N in shoots were often found after dry/wet tillage or dry tillage. The lowest values were after zero tillage, with values usually intermediate after wet tillage.

The two series of data about the 1971-A season represent two replicates of the same trial. The left column refers to a field that had been puddled for five consecutive seasons, the right column to a field that was usually dry-plowed, until the season before the trial, when it was puddled. The influence of previous tillage on the present soil structure was not investigated.

9.1.2 Split dressing

The total amount of urea was split into four dressings applied at active tillering, panicle initiation, panicle differentiation, and flowering. The effects of the split dressing on accumulation of N in shoot during certain stages of plant development will be presented. Table 61-1 gives the effect of N applied on the 32nd day (active tillering), comparing the N present on the 54th day in plants that were fertilized with that in unfertilized plants. The data are means of duplicate samples.

Rice shoots of the unfertilized dry and dry/wet tillage plots accumulated equal amounts of N, and the N in shoots of the zero tillage plots was less than half that in shoots of the two former plots. With dry tillage, urea dressing lowered the N accumulated in shoots. Only little response was obtained after the second dressing. For the other tillage treatments, urea raised the amount

Table 61. Effect of urea application (expressed as N) at different growth stages on nitrogen accumulation in shoots (kg/ha).

Tillage	Increase of nitrogen in shoots				Growth stage at which effect of urea dressing was studied
	1. between Days 0 and 54, after dressing at Day 32				
	0 kg/ha	19.2 kg/ha	difference in kg/ha	difference as % of supply	
wet	24.0	29.6	+5.6	+29	
dry/wet	37.6	44.0	+6.4	+33	active tillering
dry	36.0	33.8	-2.2	-11	
zero	16.7	24.4	+7.7	+40	
	2. between Days 54 and 73, after dressings at Days 32 and 61				
	(a)				
	0+0 kg/ha	0+28.2	difference in kg/ha	difference as % of a supply	
wet	11.6	15.8	+ 4.2	+15	
dry/wet	22.6	37.4	+14.8	+52	panicle initiation
dry	28.2	32.1	+ 3.9	+13	
zero	9.5	22.7	+13.2	+47	
	(b)				
	19.2+0	19.2+28.2	difference in kg/ha	difference % of supply	
wet	2.4	19.7	+17.2	+ 61	
dry/wet	20.2	30.4	+10.2	+ 36	
dry	28.2	50.8	+22.6	+ 80	
zero	2.8	34.0	+31.2	+110	
	3. between Days 73 and 118, after dressings at Days 32, 61 and 81				
	19.2+28.2 +0	19.2+28.2 +28.2	difference in kg/ha	difference % of supply	
wet	8.3	15.3	+ 7.0	+26	
dry/wet	- 4.0	8.1	+12.1	+43	panicle differentiation
dry	-18.6	-2.6	+16.0	+57	
zero	16.0	6.0	-10.0	-35	
	4. between Days 92 and 118, after dressings at Days 32, 61, 81 and 96				
	0+28.2+28.2 +0	0+28.2+28.2 +19.2	difference in kg/ha	difference as % of supply	
wet	- 1.9	+ 5.5	+ 7.4	+ 39	
dry/wet	-19.8	- 6.8	+13.0	+ 68	flowering
dry	+ 1.1	+25.1	+24.0	+125	
zero	- 9.4	+ 2.2	+11.6	+ 60	

of N in shoots. The response to fertilizer N was independent of the amount accumulated in shoots from unfertilized plots.

Table 61-2a gives information on the effect of urea applied on the 61st day after sowing (panicle initiation). The effect was examined in plants harvested on the 73rd day after sowing.

The accumulation of N in shoots of unfertilized plots between the 54th and 73rd day after sowing was high after dry and dry/wet tillage, and low for the other two treatments. The response to urea was large for the dry/wet and zero tillage, and considerably lower for the other two treatments.

Table 61-2b compares data on N accumulated in plants, that had all received urea at the first date (Day 32) but of which half had also received urea (28.2 kg/ha) on the second date (Day 61). The response to N was again estimated on Day 73.

Comparison of data presented in Table 61-2b with those of Table 61-2a shows that the influence of tillage treatment on fertilizer efficiency depended on whether N was applied early in development of the rice plant. A dressing at the first date increased nitrogen withdrawal after the second dressing, except for dry/wet tillage. This increase was largest after dry and zero tillage. If wet-tilled and zero-tilled plots received N at the first date but not the second, hardly any N accumulated in shoots between the 54th and 73rd day. For the dry and dry/wet tilled plots, the accumulation was little affected by N dressing at the first date, because of the high level of N in plants at the time of the second dressing.

For dry tillage, there was a large N accumulation in plants not fertilized at the second date but the response in plants that were fertilized at that date was still large. This response was much lower after dry/wet tillage. The highest response was after zero tillage, where plants accumulated more N than was applied as fertilizer on the 2nd date.

Table 61-3 gives information on the response to N applied on the 3rd date (Day 81: panicle differentiation).

For dry and dry/wet tillage in which the accumulation of N during the previous stages was large, the accumulation during the third period was low or negative, indicating that total accumulation then decreased. On the zero-tilled plots, the trend is different: there, the plants that received fertilizer at the third date accumulated less nitrogen than plants that had not received a third dressing. For zero tillage, early dressings seemed to have a large influence on nitrogen withdrawal in later stages of plant growth.

The highest efficiency of the third dressing was for dry tillage, but there the N served mainly to offset the decrease in accumulation of N for plants that did not receive N at the second date.

Table 61-4 gives gains and losses of N for plants that did or did not receive fertilizer N on the fourth date (Day 96 flowering).

During this period, N was usually lost from plants that did not receive fertilizer at the fourth date. An exception formed the dry-tilled plots. There the plants lost a considerable amount of N during the third period. This loss was offset by more than 100% recovery of N applied on the 96th day.

For the other treatments, the losses of N by plants that did not receive fertilizer N at the 4th date, were almost eliminated by a late dressing. For dry/wet tillage, where the loss of N was highest, a late dressing offset this loss only partially.

These field trials with variety Apura agree to some extent with those obtained with varieties Awini and Acorni in pot experiments (Section 8.1), for fertilizer efficiency. An early dressing resulted in low recovery; for a later dressing, recovery was low for the wet tillage and high for dry tillage.

Data on recovery of total amounts of fertilizer N applied in different distribution patterns during the growing season, as measured in shoots on Day 118, are given in Table 62. Recovery varied from 10 to 75%. It was low for wet tillage, being maximum when high applications were made at both the 2nd and 3rd dates. For dry/wet tillage, omission of the 2nd dressing resulted in maximum recoveries at a low N rate. For dry tillage, different N application patterns caused small differences in recovery. Absence of a third dressing resulted in lowest recoveries of N in the shoots, except for zero tillage where the first dressing led to high recoveries.

Table 62. Recovery of fertilizer N applied at various growth stages for different tillage treatments

Urea distribution kg/ha	Total N kg/ha	Recovery %			
		wet tillage	dry/wet tillage	dry tillage	zero tillage
40-60- 0- 0	47.4	10	11	17	75
40- 0-60- 0	47.4	13	36	31	23
0-60-60- 0	56.4	11	11	32	14
40-60-60- 0	75.6	20	26	20	33
0-60-60-40	75.6	19	27	57	26

9.1.3 Way of applying N

The usual way of applying N in the Wageningen scheme is as urea pellets from an aeroplane on to the surface-drained soil. In all trials so far, this procedure was used. In the present trial, various means of applying N were practiced.

Ten Have (1967) showed that yields were higher after application of nitrogen to a drained surface than to a flooded surface. Almost all trials reported by Ten Have were with dry/wet tillage. My subsequent trials showed that soil tillage influences mineralization of organic nitrogen, so the influence of variation in fertilizer application on the growth of rice on soils was reinvestigated after different soil tillages.

Three ways of applying N were included: (1) urea pellets to a flooded surface; (2) urea pellets to a drained surface; and (3) urea solution sprayed onto rice leaves. The three methods of N application were tried with two water management systems: (1) 4-day surface drainage period, (2) continuous flooding. Urea was applied at two rates (48 and 76 kg N per ha) in two equal dressings at panicle initiation and panicle differentiation to wet-tilled and dry-tilled soils. The accumulation of N in rice shoots is presented in Table 63. The data are means of analyses on duplicate samples.

When urea was applied to a drained surface, the land was first allowed to drain for two days before the N application, and was then reflooded after two more days. In one treatment, urea was applied to a reflooded soil 1 day after surface drainage for 4 days.

Accumulation of N in shoots on Day 63, just before the second dressing, was low for wet tillage and high for dry tillage. These differences were still present on Day 106. When the total accumulation of N in shoots was compared for plots with and without surface drainage, values were higher with surface drainage, irrespective of whether the urea was applied before or after reflooding.

In general, the response of the rice plants to foliar dressing was poor. Consequently the recovery of N was low. The only exception was N applied in low amounts to leaves on wet-tilled plots without surface drainage.

When N was applied to flooded soil, without previous surface drainage, recovery of fertilizer N was never higher than 40%. Higher values were obtained with surface drainage. Recovery was then greater when urea was applied to a drained surface. Usually, recovery was higher for the lower rate of N. A notable exception was the high recovery of fertilizer N when a total of 76 kg N was

Table 63. N accumulated in rice shoots, as affected by the way of applying urea, by tillage, and by water management

Treatment	Amount of N kg/ha	Urea applied to *	Amount of N accumulated in shoots (kg/ha) 63th day	106th day	Difference	Difference due to fertilizer	Recovery of N (%)
no surface drainage dry tillage	0 + 0		26.9	47.5	20.6	0	-
	24 + 24	leaves	26.9	52.9	26.0	5.4	11
	24 + 24	water	26.4	63.2	36.8	16.2	33
	38 + 38	leaves	30.8	62.6	31.8	11.2	14
	38 + 38	water	29.7	71.7	42.0	21.4	28
no surface drainage wet tillage	0 + 0		14.5	28.2	13.7	0	-
	24 + 24	leaves	13.3	42.2	28.9	15.2	31
	24 + 24	water	14.7	47.6	32.9	19.2	40
	38 + 38	leaves	13.1	34.8	21.7	8.0	10
	38 + 38	water	10.6	38.0	27.4	13.7	18
surface drainage dry tillage	0 + 0		31.9	47.6	15.7	0	-
	24 + 24	leaves	36.2	53.6	17.4	1.7	4
	24 + 24	water	35.9	74.5	38.6	22.9	48
	24 + 24	soil	28.8	69.3	40.5	24.8	52
	38 + 38	water	27.7	82.7	55.0	29.3	39
	38 + 38	soil	24.7	95.6	70.9	55.2	73
surface drainage wet tillage	0 + 0		19.6	35.6	16.0	0	-
	24 + 24	leaves	19.6	39.0	19.4	3.4	7
	24 + 24	water	21.7	53.1	31.4	15.4	32
	24 + 24	soil	18.7	56.3	37.6	21.6	45
	38 + 38	water	19.5	43.3	23.8	7.8	10
	38 + 38	soil	21.3	65.5	44.2	28.2	37

* 1th dressing 68 days after sowing
2nd dressing 82 days after sowing

applied per ha to drained soil after dry tillage.

In the absence of surface drainage, differences between dry and wet tillage in recovery were not consistent. For 48 kg N applied per ha, the recovery was higher with wet tillage; for 72 kg N per ha, the recovery was higher for dry tillage.

With surface drainage, the recovery of N applied to soil or water was consistently lower after wet tillage at both N levels.

With wet tillage, an increase in N applied from 48 kg to 72 kg per ha, reduced the recovery by a third or half, independent of water management, whereas with dry tillage the recovery was reduced by only a fifth.

For unfertilized plots, surface drainage *per se* did not increase accu-

Table 64. Recovery by rice plants of fertilizer N as affected by the amount and way of application, by tillage and by water management

Water management	Nitrogen application to	Recovery of applied N			
		48 kg N/ha		76 kg N/ha	
		wet tillage	dry tillage	wet tillage	dry tillage
-surface drainage	leaves	31	11	10	14
	water	40	33	18	28
+surface drainage	leaves	7	4		
	water	32	48	10	39
	soil	45	52	37	73

mulation of N by rice plants. For fertilized plots, however, surface drainage promoted accumulation after dry tillage if the urea was applied in water, whereas surface drainage lowered the withdrawal after wet tillage. This phenomenon can also be observed in the summarized data on recovery in Table 64.

9.1.4 Additional data on varieties Awini and Acorni

The data presented in the previous section pertained to the late-maturing variety Apura with a growth period of 145 days.

The early-maturing varieties Awini and Acorni (growth periods 125 and 110 days, respectively), were grown on dry- and wet-tilled soils with and without fertilizer. Shoot samples were taken on Days 35, 58 and 99. When fertilizer was applied, 85 kg N per ha was split between three dressings. For Acorni, it was applied on Days 30, 46 and 64; for Awini on Days 30, 64 and 78 (Field Trial 6; section 3.3). The accumulation of N at the various sampling dates is recorded in Table 65.

Table 65. Nitrogen accumulated in shoots (kg/ha) of the varieties Awini and Acorni, as influenced by tillage, and 0 or 85 kg N/ha at three sampling dates

Sampling dates (days after sowing)	Awini				Acorni			
	wet tillage		dry tillage		wet tillage		dry tillage	
	0 N	85 N	0 N	85 N	0 N	85 N	0 N	85 N
29	27		23		19		24	
58	31	39	34	32	42	44	37	44
99	54	75	49	77	50	67	57	63

Only at the first sampling date were the results comparable for the two varieties. The different lengths of the cropping season of the two varieties caused subsequent samplings to fall at different stages of growth and at different intervals after the last dressing.

At the first sampling, Acorni accumulated more N after dry tillage and Awini after wet tillage. At subsequent dates, the differences for the two varieties in N accumulated on soils between tillage treatments were slight compared to the differences encountered for Apura.

9.2 ACCUMULATION OF NITROGEN IN SOIL

In those areas of Surinam where two rice crops per year are grown, nitrogen fertilizer is commonly used. The nitrogen fertilizer is applied in the form of urea. Formerly, ammonium sulphate was used. Ten Have showed (1967) that urea and ammonium sulphate were equally efficient in raising grain yields. Use of urea lowered transport costs, so reducing prices per unit of nitrogen.

Urea is applied as pellets. After application, urease activity in the soil catalyses hydrolysis of urea under moist conditions to NH_4, which may be taken up by plant roots. Alternatively, the NH_4 may be partly and temporarily immobilized by microbes. Under aerobic conditions, the NH_4 may be nitrified to nitrate. If so, nitrate is the form in which nitrogen is absorbed by plant roots. However, if after nitrification anaerobic conditions exist, nitrate is denitrified to elemental nitrogen or to dinitrogen oxide which will be lost from the soil.

In a flooded rice soil, the surface layer some millimetres thick ordinarily remains aerobic. Surface drainage causes fluctuation in the boundary between aerobic and anaerobic zones of the topsoil. It also fluctuates with oxygen content of the irrigation water. If the aerobic zone gets thinner, the nitrate formed during the aerobic period may be lost from the newly reduced zone by denitrification. All transformations of nitrogen are by microbial action. Such action is determined not only by the state of oxidation but also by other factors, such as pH and readily decomposable organic matter. Moreover, nitrogen in ionic form may diffuse across the boundary between aerobic and anaerobic zones.

Thus there is a rather complicated situation, in which it is difficult to predict the fate of nitrogen applied as urea. Nevertheless, since under the soil management practiced in the Wageningen polder, NH_4 is likely to be the main form of nitrogen available to rice plants, analysis of plant-available N was restricted to NH_4. To study the effect of tillage on the fate of nitrogen applied in Field Trial 5, 80 kg urea per ha was applied to wet-tilled and dry-tilled plots. Urea was applied:

1. Half-way through a four-day period of surface drainage.
2. To a flooded soil, the day after a four-day period of surface drainage.
3. To a permanently flooded surface.

NH_4 was estimated in samples of soil with and without the presence of rice roots. To obtain soil from which roots had not extracted any NH_4, plastic tubes 20 cm long, diameter 10 cm, were driven completely into the soil between the rice plants. The soil inside these tubes will be referred to as uncropped soil. Samples of cropped soil were taken from 40-m^2 fertilized plots containing 5 of the tubes. Hence, cropped and uncropped soils were kept under similar conditions except for the presence or absence of rice roots. In the plots to be fertilized, the soil inside the tubes was covered when the rest of the plot received fertilizer. Afterwards, representative quantities of urea were added separately to the soil inside the tubes.

Samples were taken from the top 7.5 cm of cropped and uncropped soil. For a description of the methods of tube placement, sampling and soil analysis, see Sections 3.1 and 7.2. Soil samples were taken on various days after application of the fertilizer. Control samples were taken from plots that had not received any fertilizer. Variations in the content of soil NH_4 as influenced by fertilizer application, cropping, soil-tillage treatment and water management are shown in Figure 62. Soil sampling started on 5 August 65 days after sowing.

For a certain fertilizer treatment, the shaded areas in the figures represent differences in contents of NH_4 between cropped and uncropped soil; in other words, the amounts of NH_4 withdrawn by rice plants from a given mass of cropped soil.

The relative constancy of soil NH_4 in uncropped and unfertilized soil indicates that during the experimental period little mineralization of organic nitrogen took place. The NH_4 present at the start of the experimental period was gradually withdrawn by rice roots in the cropped soil.

A comparison of decreases in soil NH_4 and concurrent increases in nitrogen accumulated in the aerial parts of the rice plants is presented in Table 66. In the wet-tilled plots the increase in plant N was almost equal to the decrease in soil N and, in the dry-tilled plots, the increase in plant N exceeded the decrease in soil N. The latter finding may result from withdrawal by rice roots from soil below 7.5 cm depth.

For both tillage treatments and all three water-management treatments, the soil NH_4 increased after urea application. For each of the three water-management treatments, the values were found to be higher on the wet-tilled plots than on the dry-tilled plots. For both tillage treatments, soil NH_4 de-

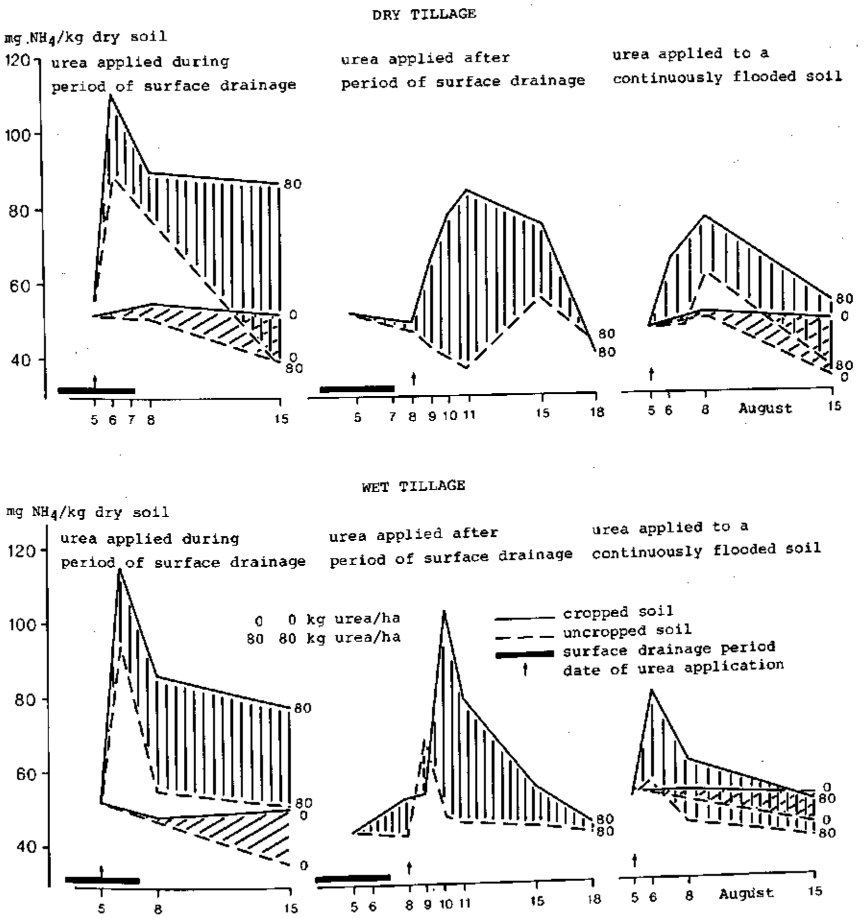


Figure 62. Effect of tillage and water management on soil ammonium of cropped and uncropped soils on various days after dressings of 0 or 80 kg urea/ha

Table 66. Decreases in amount of ammonium in soil and amount of nitrogen accumulated in plants (both in kg N/ha) in a 10-day period, with and without surface drainage on unfertilized soil.

Tillage	surface-drained for 4 days		not drained	
	decrease in soil N	increase in plant N	decrease in soil N	increase in plant N
wet	6.2	6.4	2.8	3.2
dry	5.6	7.6	6.6	10.2

creased most rapidly when urea was applied to a drained surface and most slowly when urea was applied to a continuously flooded surface.

In uncropped soil, the increase in soil NH_4 after application of urea to a flooded surface (either with or without drainage for 4 days before urea application) disappeared within 10 days of application. In these treatments, applied urea or NH_4 was retained in the aerobic top of the soil where it would be converted into nitrite and nitrate, and subsequently lost by denitrification. In contrast, urea applied to a drained surface was washed either as urea or NH_4 deeper into the soil by the re-entering irrigation water where it was stored in the reduced zone below the top layer and thus protected against nitrification and subsequent denitrification.

Various hypotheses can be advanced about the fate of applied urea N:
-after conversion to NH_4, it may be withdrawn by plant roots
-it may be stored in NH_4 form in the soil
-it may be oxidized to nitrate
-upon nitrification, it may be lost by denitrification
-it may be immobilized in microbes
The first two hypotheses will be dealt with.

Estimates of amounts of NH_4-N withdrawn by plants may be obtained by subtracting the values for fertilized cropped soil from those for fertilized uncropped soil (Table 67). NH_4 withdrawal by plants was most when urea was applied to a drained surface, and least when urea was applied to a newly flooded surface. In the two treatments, where sizeable amounts of NH_4 were withdrawn by plants, more was withdrawn on dry-tilled than wet-tilled plots.

Estimates of the amounts of urea N stored as NH_4 in the uncropped soil can be obtained by calculating the difference between NH_4 present in fertilized and unfertilized soil (Table 68). Only when urea was applied to a drained surface, were considerable amounts of fertilizer N still present as NH_4 10 days after application. When urea was applied to a flooded surface, no NH_4 or even a negative amount of NH_4 could be recovered after 10 days.

Table 67. Differences in ammonium content (mg NH_4/kg dry soil) of cropped and uncropped soil 10 days after applying 80 kg urea per ha as affected by surface drainage and by applying urea to flooded or drained surface

Tillage	To drained surface	To flooded surface	
		after surface drainage	without surface drainage
wet	26.5	1.4	9.8
dry	48.3	-3.2	18.1

Table 68. Ammonium nitrogen stored in uncropped soil (mg N/kg dry soil) 10 days after applying urea as affected by surface drainage and by applying urea to flooded or drained surface

Tillage	To drained surface	To flooded surface	
		after surface drainage	without surface drainage
wet	+ 27.5	- 5.2	- 0.8
dry	+ 35.1	-10.7	+ 5.4

The negative results presumably originated from the use of one plot without fertilizer for each water-management system, introducing soil fertility variations in between the plots. Absence of NH_4 could be because urea applied to water can be assumed to be converted to nitrate, which may be lost through denitrification.

A dressing of 80 kg urea per hectare is equivalent to 85 mg NH_4 per kg dry soil (soil depth 7.5 cm, bulk density 0.80%). At most 55% of this amount is withdrawn by the plants after dry tillage, and only 35% after wet tillage (Table 67). Storage of the applied urea as NH_4 amounts at most to 40% after dry tillage and 35% after wet tillage (Table 68). These data refer all to the period of 10 days after one top dressing with 80 kg urea per ha.

Table 69 gives information on recovery of urea N by rice plants after dressing drained or flooded soil. In this part of the experiment, urea was added as a split dressing. At each dressing (65 and 80 days after seeding, respectively), 80 kg urea per ha were applied. The data apply to accumulation of N in rice plants, resulting from urea application, over a 41-day period.

For all three water-management systems, the efficiency of the fertilizer was higher after dry than wet tillage. After wet tillage, efficiency was only slightly influenced by variations in water-management. After dry tillage,

Table 69. Increase in nitrogen accumulation in shoots (kg N/ha) and in % N of applied urea of fertilized over unfertilized plants as affected by surface drainage and applying urea to flooded or drained surface

Tillage	To drained surface		To flooded surface			
			after surface drainage		without surface drainage	
	N increase kg/ha	recovery %	N increase kg/ha	recovery %	N increase kg/ha	recovery %
wet	28	37	8	10	14	18
dry	55	73	29	39	21	28

surface drainage enhanced recovery irrespective of whether urea was applied during or after surface drainage.

The results presented in Figure 6.1, pertaining to dry tillage, already implied that NH_4 formed from urea applied to a flooded surface rapidly disappeared from the soil, also when the soil was left uncropped. In the aerobic top layer of soil, this NH_4 is converted to nitrate which subsequently may be lost by denitrification. The low recovery after wet tillage in Table 69 supports this inference. However the high recovery after dry tillage in Table 69 suggests that after dry tillage nitrate may indeed be formed when urea is applied to a flooded surface but that dry-tilled soil remains aerobic deep enough to prevent nitrate from becoming lost by denitrification. The nitrate protected against denitrification may be absorbed by rice roots; hence the high recovery of fertilizer N when urea was applied to a flooded surface shortly after surface drainage. Only when the soil remained continuously flooded was dry tillage ineffective in protecting nitrate formed against denitrification, as evidenced by the comparatively low recovery in Table 69.

SUMMARY CHAPTER 9

1. The accumulation of nitrogen in unfertilized rice shoots was dependent on tillage. The influence that tillage exerted on N accumulation differed according to growth stage and increased at tillering in the order: zero, dry, wet, dry/wet; at panicle initiation in the order zero, wet, dry, dry/wet, and at panicle differentiation in the order zero, wet, dry/wet and dry.

   With respect to water management in the wet-tilled treatment four-day surface drainage periods resulted in a decline in the level of soil ammonium. This decline was caused by nitrification, whose rate exceeded that of ammonification brought about by soil drying at surface drainage. The increase N accumulation in rice shoots suggests that the nitrate formed was taken up by the rice plants before a major portion of it was lost by denitrification.

   After dry tillage, surface drainage left the soil ammonium level unaltered, suggesting that increased ammonification due to surface drainage is balanced by the decrease in ammonium caused by nitrification. A lowered accumulation of N in rice shoots may have resulted from an increased rate of denitrification in this treatment.
2. The recovery of the fertilizer as measured by the increase in accumulated nitrogen in the rice plant is influenced by the way N was applied. During hydrolysis of urea, the nitrogen is made available to plants as it is con-

verted to ammonium. Hydrolysis proceeded fastest in the wet tillage treatment in combination with a surface-drainage period. The ammonium N is protected against nitrification and subsequent denitrification, when after surface drainage, reflooding causes the ammonium to be translocated downwards to the reduced zone. Such a translocation was found to be more complete with dry tillage than wet tillage. Consequently recovery of fertilizer N was highest when

-N was applied to a drained surface

-N was applied to a dry tilled soil

Puddles on a drained field accelerates the hydrolysis of urea and the subsequent formation of nitrate, and upon reflooding, reduces the movement of water into the dried soil. For these reasons, the presence of such puddles should be avoided as much as possible. Surface run-off during a drainage period was found to be promoted by careful levelling of the soil surface, by field trenching with the aid of a trench-wheel, and by additional trenching of any puddles present after sowing.

Availability of soil nitrogen. Up to the tillering stage, the supply of soil ammonium is sufficient for normal growth. Afterwards, in the wet and zero treatments, the amount of soil ammonium was inadequate to meet the requirements of the rice plant. In the dry and dry/wet treatments, before tillering, the rate of ammonification was high. In the dry/wet treatment, the ammonium formed was rapidly absorbed by the plants, whereas in the dry treatment, this absorption took place also past the tillering stage. In the dry and dry/wet treatments up to panicle initiation, the rate of ammonification remained sufficient for N nutrition of the rice plants, thus leading to low rates of recovery of added fertilizer N. In the other two treatments (wet and zero), the formation of soil ammonium was inadequate, so that high recoveries of fertilizer N were found.

In the dry/wet treatment, the high amount of N accumulated in the rice plants at tillering was an additional cause of a low recovery of fertilizer N applied at tillering.

The distribution. In the treatments wet, zero, and dry, an N application at tillering induced a high recovery of a subsequent N application. In the wet and zero treatments, a single application at tillering reduced uptake of soil ammonium in the period after tillering. Such a reduction was probably caused by a less dense and more superficial root system, which functioned well in utilizing fertilizer N but made less use of soil ammonium.

In the treatments dry and dry/wet, a single N dressing at tillering did not reduce utilization of soil ammonium. In these treatments, the root systems were likely to have developed more uniformly throughout the plow layer, and also formation of soil ammonium can be expected to have taken place throughout the plow layer.

In the dry treatment, ammonium formed from urea is believed to have spread over a larger volume of soil, causing a higher temporary immobilization and a belated recovery of this ammonium by rice plants.

In the dry and dry/wet treatments, with the higher dry matter production, urea application at panicle initiation, and not followed by subsequent applications, reduced the amount of nitrogen accumulated in rice plants. Sometimes less nitrogen was present in plants approaching maturity than at earlier stages. Losses were assumed to be due to dying of lower leaves and to leaching of nitrogen from the leaves during rain periods. If a dressing at panicle initiation was followed by one at panicle differentiation recoveries were higher.

3. The percentages recovery of fertilizer N per application and for various combinations of application varied among tillage treatments.

In the wet treatment, the recoveries for single dressings were low (15-30%), with the exception of the dressing at panicle initiation, which had been preceded by a dressings at tillering (60%). The recovery at grain setting was highest (although not more than 20%) for a combination of dressings at tillering, panicle initiation and panicle differentiation.

In the dry treatment, the recovery of N applied at tillering was low (-11-13%), but high for subsequent single dressings (43-80%). At grain setting, the recovery was highest (57%) for a combination of dressings at panicle initiation and differentiation, and at flowering.

In the dry/wet treatment, the recovery was low when N was applied at tillering and with a dressing which had been preceded by a dressing at tillering (33-43%). The recoveries were higher (52-68%) for all other single dressings. At grain setting, the recovery was highest (37%) for a combination of applications at tillering and panicle differentiation.

In the zero treatment, the recoveries of single dressings were high (40-110%), except for one at panicle differentiation preceded by dressings at tillering and panicle initiation. At grain setting, the recovery was highest (73%) for a combination of dressings at tillering and panicle initiation.

The information supplied in the foregoing paragraphs all apply to the variety Apura. Acorni behaved similarly. The variety Awini had accumulated more N at tillering in the dry treatment than in the wet treatment.

10 Grain yield aspects

The amounts of exchangeable NH_4 resulting from mineralization of soil organic nitrogen are influenced by the type of tillage (7.1). In turn, the amounts of exchangeable ammonium in soil affect plant growth, as experienced in the series of pot experiments (8.1). Fertilizer nitrogen influenced the level of soil ammonium. Finally, in pot experiments (8.1) and field trials (9.1), a relationship was found between N applied as fertilizer and the amounts of N accumulating in shoots. The influence of fertilizer ammonium on the level of soil ammonium and on the accumulation of nitrogen in shoots depended on the type of tillage.

Attention is now drawn to three effects of application of fertilizer N on grain yield: (1) effect of the total amount of N applied per cropping season; (2) effect of distribution of fertilizer N between several split dressings; (3) effect of the various ways in which the fertilizer N was applied.

Sections 10.1 and 10.2 present results with the variety Apura in a study on the relationship between N application and grain yield for the four main tillage treatments (wet, dry/wet, dry and zero). Section 10.1 stresses the effect of the total amounts of N applied, with attention also to the effects of variations in the distribution of the N over the various split dressings. Information on plant parameters related to grain production is also supplied. These parameters are percentage unfilled grains, 1000-grain weight, straw/grain relation, the percentage of tillers that are productive, and the number of panicles.

Section 10.2 discusses the influence of a various distribution patterns of total N at two levels over four dressings on the above plant parameters.

Section 10.2 discusses the influence of various distribution patterns Apura, Awini and Acorni. These trials were with the two tillage treatments that were also used in the pot experiments, namely clod and mud structure. For both tillage treatments, the soil had previously been dried to the same extent (10% moisture).

10.1 AMOUNTS OF FERTILIZER NITROGEN

This fertilizer trial (Trial 2) included the four tillage treatments (2.3). On the zero-tilled plot, the rice crop (the third one grown in succession without tillage) failed (8.2). Data on grain yields and other parameters were obtained for the remaining three tillage treatments.

Fertilizer was applied as urea at amounts up to 270 kg per ha. At each split dressing, the amounts were up to 90 kg urea per ha. Time and stage of plant development at which topdressings were applied, were as follows:

1	30 days after sowing	active tillering
2	65 days after sowing	panicle initiation
3	80 days after sowing	panicle differentiation

Grain yields are presented for each tillage treatment separately in Figure 63. Points representing treatments that differed in amounts of N applied at only one of the three dates of application are connected. For all tillage treatments, rice responded to N fertilizer but response varied widely between tillage treatments.

Variations in grain yield relative to how N was distributed over the three topdressings were small for the wet and dry tillage treatments, and large for the dry/wet tillage treatment. For wet tillage, rice did not respond beyond 90 kg of urea applied per ha. Yield was lower than for the other two tillage treatments.

For dry/wet tillage, the distribution of urea between the dressings had a large influence on grain yield. The first dressing was always ineffective. Equal distribution of large amounts of urea between the dressings was particularly ineffective. A dressing of 30 kg urea at the third date was more effective than three dressings of 90 kg each. The combination 0-30-90 kg urea was most effective. In general, omission of a first dressing increased yield.

With dry tillage, the effects of split dressings were intermediate to those with dry/wet and wet tillage. The negative influence of N applied at the first date was present, but much less than for dry/wet tillage. Rice responded to amounts of urea up to 120 kg when divided 0-30-90 over the three dates. The maximum yield for that distribution was slightly higher than for the dry/wet tillage.

The effects of N fertilizer and the tillage treatments on a few other plant parameters were also investigated (Figure 64).

No relationship could be detected between the amount of N applied and the percentage of unfilled grains or the straw/grain relation. For wet and

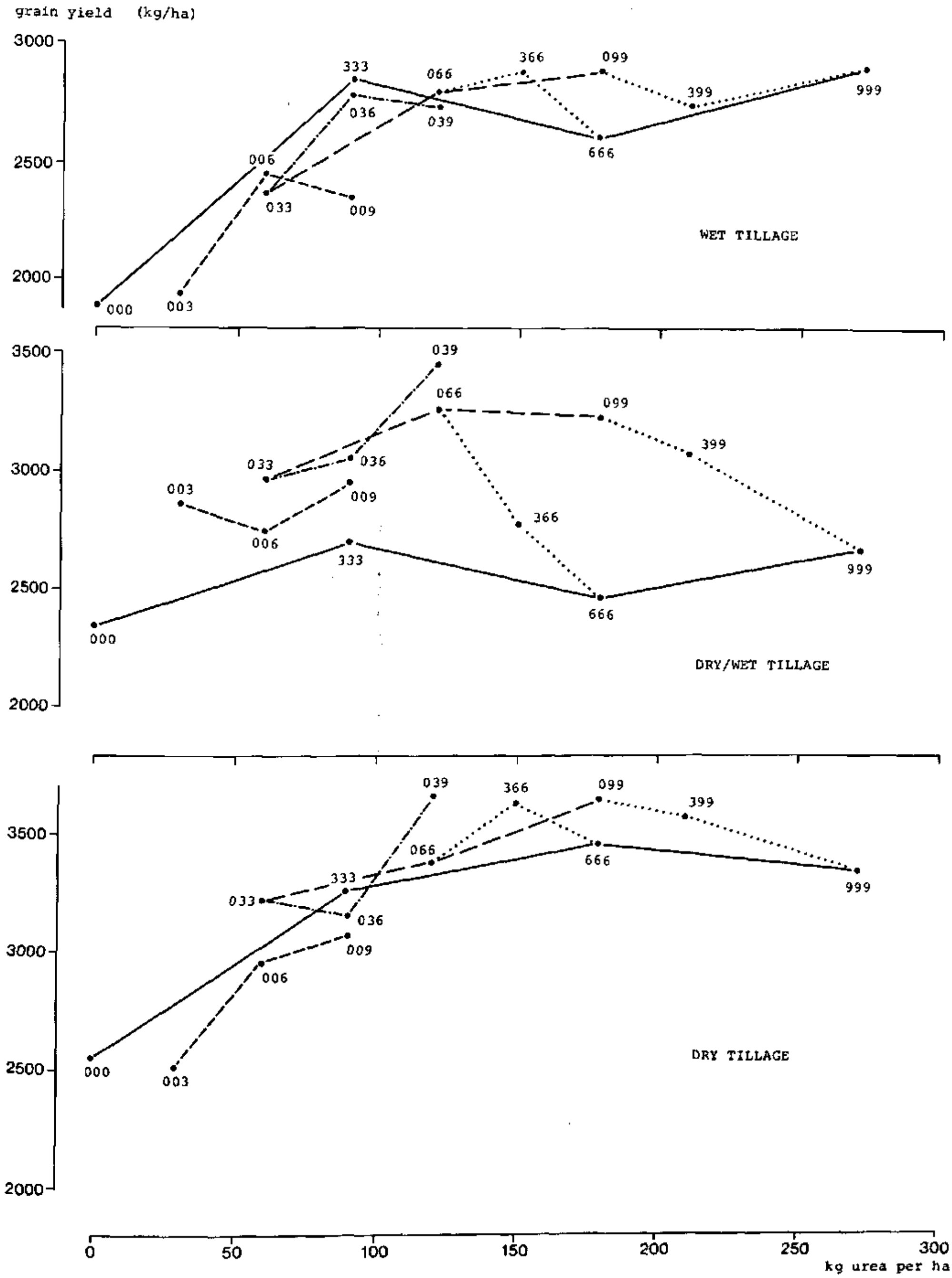


Figure 63. Effect on rice yield of different amounts of nitrogen fertilizer and different patterns of application in split dressings after three tillage treatments. The numbers indicate tens of kilograms urea applied per ha in the first, second and third dressing (e.g. 366 means first dressing 30 kg/ha, second 60 kg/ha and third 60 kg/ha).

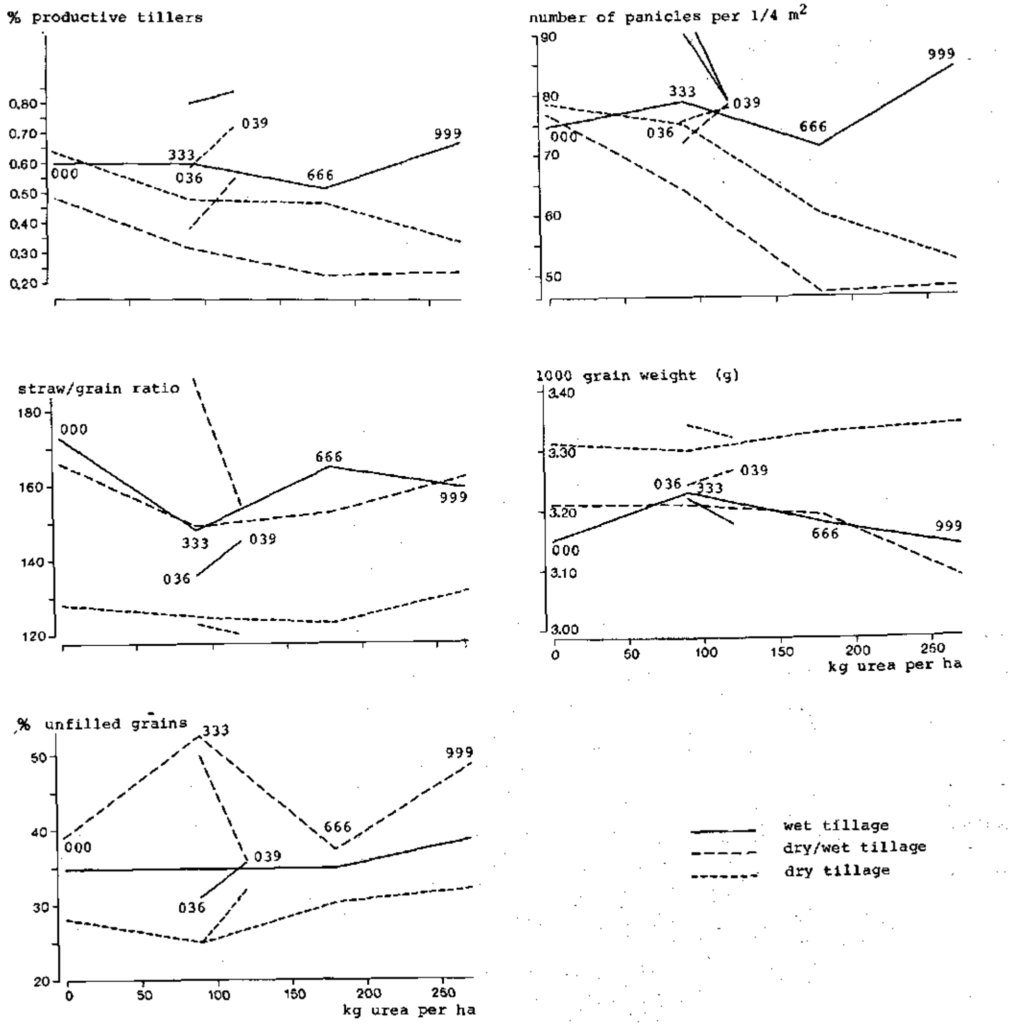


Figure 64. Effect on some plant parameters of different amounts of nitrogen fertilizer and different patterns of application in split dressings after three tillage treatments. For explanation see Figure 63.

dry/wet tillage, 1000-grain weight decreased with high levels of N distributed evenly over the three dressings. For dry and dry/wet tillage, the percentage of productive tillers and the number of tillers decreased with increasing levels of N distributed evenly over the three dressings. For all three tillage treatments, the percentage productive tillers was largest with 0-30-60 or 90. The same holds for the number of panicles after dry and dry/wet tillage.

The influence of differences in tillage on the various plant parameters are presented in Table 70. The number of tillers increased in the order wet, dry and dry/wet tillage. The number of panicles, however, was lower for dry/wet tillage than for dry and wet tillage, whereas the dry/wet-tilled plots produced the most tillers. The percentage productive tillers decreased as the number of tillers increased from a low level for wet tillage to a high level for the dry/wet tillage. The straw/grain relation was low for dry tillage and was almost equally high for dry/wet and wet tillage. For dry tillage, a low straw/grain relation was related to a low percentage unfilled grains and to a high 1000-grain weight. The opposite was found for dry/wet and wet tillage.

The content of N in the rice plant was highest after dry tillage (Table 71), presumably because of high mineralization of soil organic nitrogen in dry-tilled soil. The low amount of nitrogen accumulated in the shoots of plants in that treatment is likely to have been caused by low seedling establishment and by retarded seedling growth (8.2).

The amount of N accumulated in the shoots was highest after dry/wet tillage, because of a high seedling establishment and of rapid seedling growth.

Table 70. Influence of tillage on various plant properties

Tillage	Number of tillers per ¼ m^2	Number of panicles per ¼ m^2	productive panicles (%)	unfilled grains (%)	1000-grain weight (g)	Straw-grain relation
wet	90-140	50-90	45-90	30-40	31-33	1.4-1.7
dry/wet	150-200	45-75	25-55	35-55	31-33	1.4-1.9
dry	110-170	50-90	40-70	25-35	33-34	1.2-1.3

Table 71. Influence of tillage on nitrogen in shoots before first dressing (34 days after sowing)

Tillage	N accumulated in shoots (kg/ha)	Content of N (g/100g)
wet	21.2	2.26
dry/wet	32.6	3.10
dry	18.4	3.30

The rapid increase in dry matter production resulted from a large supply of soil ammonium.

The lower N content of the shoots in that treament for dry tillage can be accounted for by postulating a dilution of absorbed N inside the plants by rapid growth of those plants, the Steenbjerg effect.

The high seedling establishment and the rapid seedling growth after wet tillage did not lead to high N content nor yield of N, because of the low supply of ammonium from the soil.

With this interpretation, the relationship of level of fertilizer and tillage treatment with grain yield can better be understood. In all tillage treatments, there was an increase in percentage productive tillers and in number of panicles if an even distribution of N fertilizer between the three dates was changed to a system in which the first dressing was omitted, the second dressing was low, 30 kg urea per ha, and the third high, 90 kg per ha. This system gave less tillering but a higher percentage of productive tillers, resulting in higher grain yield after dry and dry/wet tillage. With both tillage treatments, the amount of exchangeable ammonium at the start of the rice-growing season was high. Hence, any fertilizer at the beginning of the season promoted excessive tillering.

Dry/wet tillage produced most straw dry matter by combining high seed establishment, seedling growth and availability of soil ammonium. There is a risk of a canopy growing too dense, and mutual shading may cause many leaves to die prematurely. The proportion of photosynthates consumed in respiration may increase, leaving less carbohydrates available for grain production. A high straw/grain relation and a high percentage unfilled grains accompanied such a development. An early application of N fertilizer and a large amount of fertilizer N at the second date increased the number of unproductive tillers after dry/wet tillage.

Dry tillage led to a moderate number of tillers, which were moderately effective in producing panicles. The low straw/grain relation, the low percentage unfilled grains and a favourable 1000-grain weight accounted for the high grain yields at this tillage treatment.

In spite of high values of most of the measured plant parameters, grain yields on wet-tilled plots were low. The number of grains per panicle, which was not measured, may have been responsible for the low grain yields in this tillage treatment. The low efficiency of fertilizer applied at panicle differentiation (9.1) may have caused the low numbers per panicle.

10.2 DISTRIBUTION OF FERTILIZER NITROGEN

The distribution of fertilizer nitrogen over the dates of dressing is of large influence on grain yield (10.1). Some hypotheses were advanced about the relationship between N dressing and grain production. Only a few distribution patterns were employed, in which the fertilizer nitrogen was not distributed evenly between the dates. The relationship between fertilizer distribution and grain yield will now be investigated more systematically for variety Apura (Trial 3; Section 3.3). The total amount of N applied was either 120 or 180 kg of urea per ha. These amounts were distributed between 4 dressings at 4 stages of development, which have been earlier mentioned in Section 10.1.

To visualize the patterns of N distribution and their effects on grain yield, triangular diagrams are used, like those for particle-size distribution in soils (Figure 65). The corners of the triangles indicate the total amount of urea applied at the different dates. When the total amount of N was split between two dressings only, such a situation is represented in the diagram by a point on the line connecting two dates. The distances from such a point to the neighbouring corners of the triangle are inversely proportional to the fractions of total fertilizer applied at the two dates of application. Distribution over more than two dressings are represented by points inside the triangle by parallel displacement of the points from the sides of the triangle. The amount of urea applied in tens of kg per ha is shown in the diagrams of Figure 65. The yields for the four tillage treatments are placed in the diagrams and indicate the fertilizer distribution pattern.

The response of rice to distribution of N differed according to total amount of urea applied.At 120 kg urea, on the wet-tilled soils, yields were promoted by a large amount at the first date, whereas for the other tillage treatments high yields were obtained when no fertilizer was applied at the first date.

At 180 kg urea, yields were generally promoted by applying most at second and third dates. For dry and dry/wet tillage, highest yields were obtained with one-third of the N at the second, and two-thirds at the third date. There, N applied at the first and fourth dates had little beneficial influence on grain yield. For wet tillage, equal amounts of N at the second and third dates, with little at the fourth date, were most beneficial to grain yield. For zero tillage, the effect of distribution of N on yield was similar to that for dry and dry/wet tillage, but less distinct.

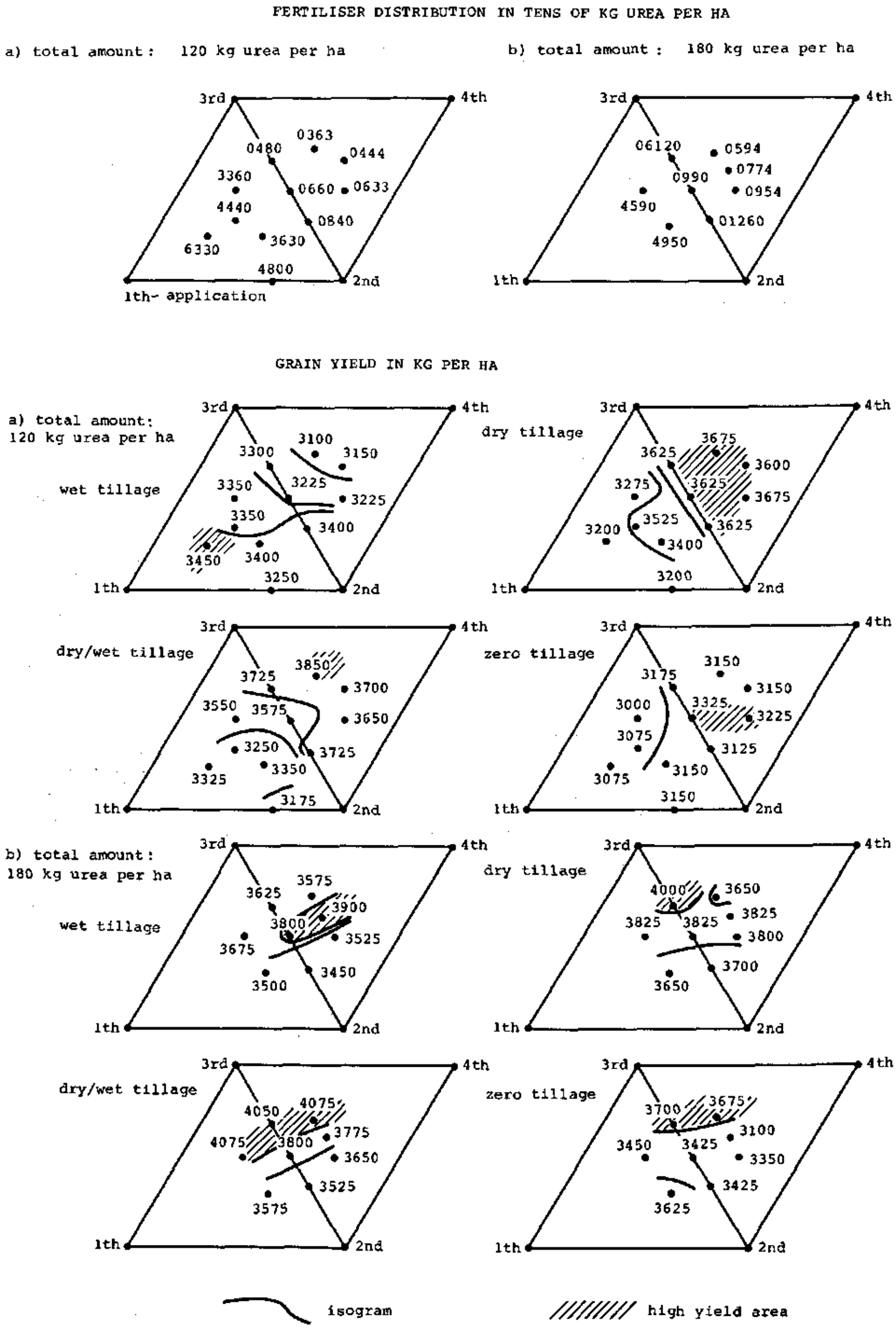


Figure 65. Diagrams of distribution of nitrogen fertilizer at two levels of total fertilizer and the corresponding grain yields after four tillage treatments. The numbers indicate tens of kilograms urea applied per ha at first, second, third and fourth dressing (as Figure 63). Hatched parts are high-yield areas, though the differences are not always significant.

For all tillage treatments, maximum yields were obtained at the higher level of total urea (Table 72). The differences in maximum yields between tillage treatments were smaller at 180 kg than at 120 kg urea per ha. The differences in yield caused by differences in fertilizer distribution were high for dry/wet tillage at both fertilizer levels. These differences were moderate for dry and wet tillage. For zero tillage, the difference was small at the low fertilizer level and high at the high fertilizer level.

At 120 kg total urea per ha, lowest yields were obtained when fertilizer N was applied at the first date, except for wet tillage, for which lowest yields were obtained when much fertilizer was applied at the third date. At 180 kg total urea per ha, use of fertilizer at the first date did not lower yields. There, yields were lowest when most N was applied at the second date.

The way in which rice responded to distribution of fertilizer was influenced by the extent to which soil N became available during a growing season. For maximum yields, low amounts of exchangeable soil ammonium resulting from wet tillage caused a need for fertilizer at the first date, if the lower amount of N was applied. Omission of fertilizer N at an early date, in combination with a low second dressing, considerably reduced grain yield. On the other hand, at the high level (180 kg/ha), highest yields were obtained with an equal distribution of the urea between the second and third date with some at the fourth date.

Table 72. Summary of grain yields and corresponding split dressings for different tillage treatments

Tillage	Urea distribution giving highest yield		Urea distribution giving lowest yield		Differences in yield (kg/ha)
	dressing (kg/ha)	yield (kg/ha)	dressing (kg/ha)	yield (kg/ha)	
	120 kg urea per ha:				
wet	60-30- 30- 0	3450	0- 30-60-30	3100	350
dry/wet	0-30- 60-30	3850	40- 80- 0- 0	3175	675
dry	0-30- 60-30	3675	60- 30-30- 0	3200	475
zero	0-60- 30-30 0-60- 60- 0	3325	40- 80- 0- 0 30- 30-60- 0	3075	250
	180 kg urea per ha:				
wet	0-70- 70-40	3900	0-120-60- 0	3700	400
dry/wet	40-50- 90- 0	4075	0-120-60- 0	3500	575
dry	0-50- 90-40 0-60-120- 0	4000	40- 90-50- 0	3650	350
zero	0-60-120- 0	3700	0- 50-90-40 0- 70-70-40	3100	600

For high grain yields on wet-tilled soils, a large amount of urea was possibly needed at the stage of growth when the second and third dressings were applied. When fertilizer N was withheld at that stage, favourable conditions at tillering may promote utilization of soil nitrogen. In any case after wet tillage, the efficiency of fertilizer N in increasing shoot N contents was relatively low (9.1).

For dry-tilled soils, the efficiency of fertilizer N in promoting the accumulation of N in shoots was low for the first dressing, whether it was applied at the first or the second date (9.1). This situation may account for a greater importance of the second dressing in producing high grain yields after dry tillage than after dry/wet tillage.

10.3 VARIETAL DIFFERENCES IN RESPONSE TO DISTRIBUTION OF NITROGEN FERTILIZER

The effects of urea and its distribution between split dressings for Apura rice grown after four tillage treatments were shown in Sections 10.1 and 10.2. Since some investigators have shown that differences in tillage did not influence rice growth and grain yield, the hypothesis was considered that the response by the variety Apura resulted from an unusual sensitivity of this variety to soil structure. An experiment was conducted in which some newly developed rice varieties were tested for their response to fertilizer N with different soil structures. These new varieties can be divided into two groups according to their genetic origin. One group represented by Acorni consists of crosses of late-maturing Surinam varieties (e.g. Apura) with early-maturing United States varieties (e.g. Bluebell). The other group represented by Awini consists of crosses of the late-maturing Surinam varieties with Asiatic early-maturing varieties (e.g. Taichung Native 1).

Influences of tillage, urea application, and its distribution, on grain yields and other characteristics were studies for the varieties Apura, Awini and Acorni. Identical, but separate trials were established for each variety (Section 3.3; Trial 8). The tillage treatments differed from those in the experiments reported in Sections 10.1 and 10.2, in that only the two soil structures used in the pot experiment (clods and mud) were employed. The clod structure was comparable to dry tillage in the field; the mud structure to dry/wet tillage with an extreme puddling after the drying of the clods.

In both treatments, the soil was allowed to dry out to 10% moisture before submergence. The tillage treatments were identical for all three varieties and were simultaneous.

For the variety Apura, the urea was distributed between four dressings; for the varieties Awini and Acorni, between three. The difference was associated with the difference in length of the growing period between the varieties. For Apura, the distribution was identical with that in Section 10.2. For the varieties Acorni and Awini, the distribution of urea N was as follows:

active tillering	25 days after sowing
panicle differentiation	46 days for Acorni; 62 for Awini
flowering	65 days for Acorni; 85 for Awini

The results are presented as triangle diagrams as in Section 10.2. First, grain yields are presented; next, data on plant performance.

The results with the three varieties should not be directly compared, since they were obtained in different trials. The responses of the varieties to soil treatment and to distribution of fertilizer N will be compared.

Apura and Acorni display similar responses to soil structural differences (Figure 66). Higher grain yields were obtained with clods than mud. The response of Awini was the reverse, with higher yields on mud than on clods.

The effect of variation in distribution of urea on grain yields was slightly different for the two soil structures (Table 73). Awini and Acorni

Table 73. Summary of grain yields and corresponding split dressings for three varieties and two soil structures, both with intense previous soil drying

Soil structure	Amount of urea (kg/ha)	Urea distribution giving highest yield		Urea distribution giving lowest yield		Differences (kg/ha)
		dressing (kg/ha)	yield (kg/ha)	dressing (kg/ha)	yield (kg/ha)	
	Apura					
mud	120	30- 60-30-0	4825	80-40- 0- 0	4325	500
clods	120	30- 30-60-0	4875	80-40- 0- 0	4250	625
mud	180	0-120-60-0	5025	0-70-70-40	4775	250
clods	180	0-110-60-0	5175	60-60-60- 0	4700	475
	Acorni					
mud	120	0-120- 0	4750	80-40- 0	4200	550
clods	120	0-120- 0	5000	80- 0-40	4275	725
mud	180	0- 90-90	4725	90-90- 0 60-60-60	4525	200
mud	180	0- 90-90	4825	90-90- 0	4550	275
	Awini					
mud	120	0-120- 0	4275	40- 0-80	3450	825
clods	120	0-120- 0	4300	80- 0-40	3300	900
mud	180	0- 90-90	4350	90-90- 0	4000	350
clods	180	0- 90-90	4150	90-90- 0	3630	500

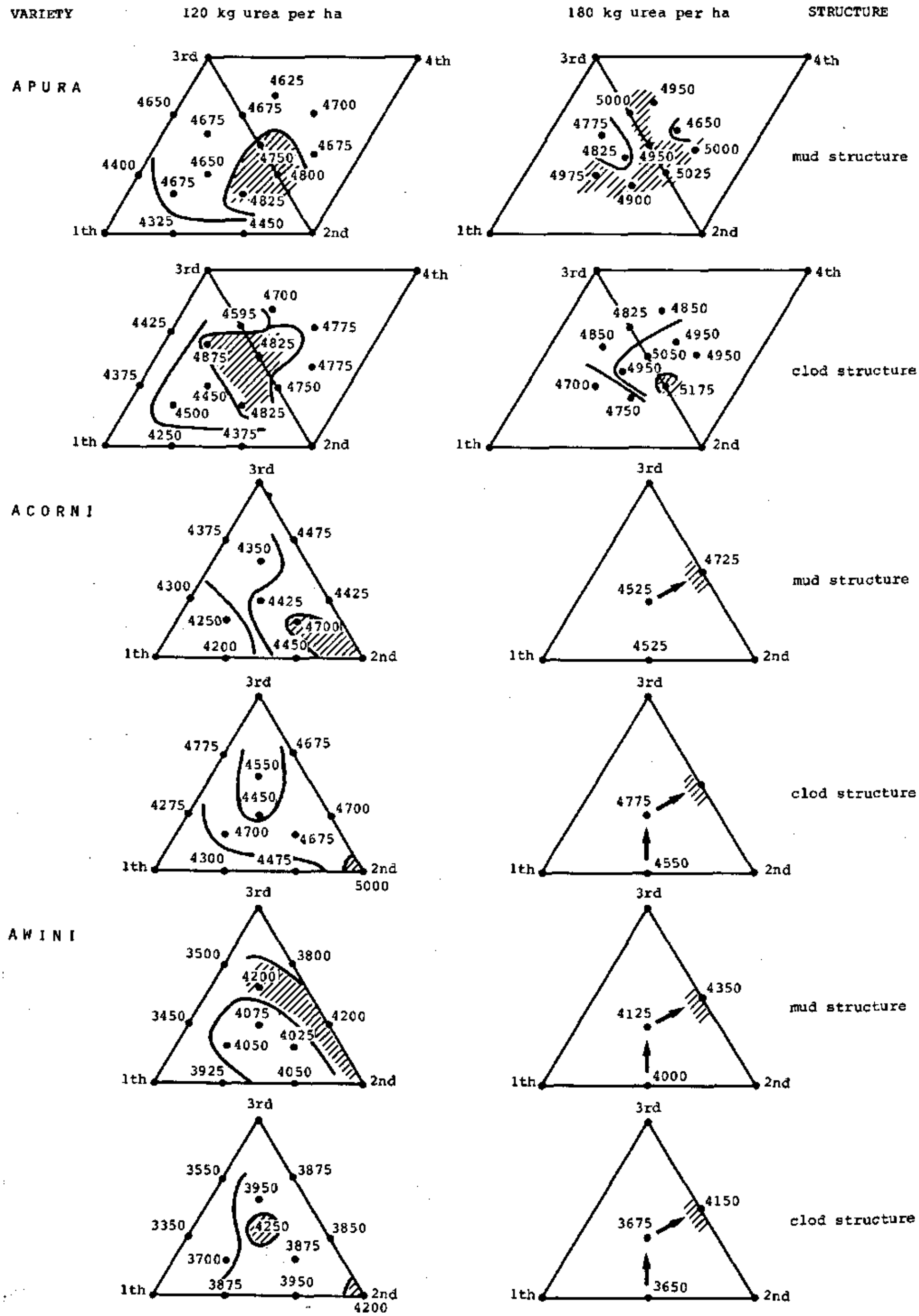


Figure 66. isogram //////// high yield area

reached maximum yields at a lower level of total urea than Apura. For Awini and Acorni, maximum yields were when the whole 120 kg urea was applied at the second date. For Apura, yields were maximum when 2/3 of a total of 180 kg urea was applied at the second date and 1/3 at the third date.

The influence of distribution of fertilizer on yield were larger with 120 kg than 180 kg urea per ha. Soil treatment also had an influence. The differences in grain yield were higher with clods than mud.

For a given variety and a given level of urea, maximum yields were generally obtained with the same N distribution for both soil structures. Hence, a difference in soil structure has little influence on how fertilizer can best be distributed over the various dates if previous soil drying before flooding is equal. Only with Apura at 120 kg/ha were maximum yields obtained for the two soil structures with different distributions of fertilizer. At 180 kg/ha, too few distribution patterns were included to allow definite conclusions.

The other parameters of plant performance, in this trial were numbers of plants, of tillers, and of panicles per 0.25 m^2 and their relations. At the start of the rice-growing season, counting frames were placed in the fields. Except for grain yield, which was measured on 40-m^2 plots, all data were obtained within the areas of the frames.

The number of tillers was found to be variety-dependent and to be influenced by seed rate (Fig. 67). The number of tillers decreased in the order Apura, Acorni, Awini, with corresponding seed rates of 90, 100 and 100 kg per ha, respectively. Mostly the number of stems increased with fertilizer applied at the first date, and with mud. Only for Acorni was an interaction found between N dressing at the first date and soil structure, in that the number of tillers was reduced in mud by early dressing.

A dressing at the first date reduced the number of panicles, except for Apura with clods, where the reverse was found.

The tiller/plant relation was higher for Awini than for Acorni and Apura, perhaps because of the low seedrate. No consistent influence of soil structure on this relation could be detected. Dressing at the early date caused the relation to increase, except for Acorni grown on mud, because of the higher number of tillers.

The panicle/plant relation decreased in the order Awini, Acorni, Apura.

Figure 66. Diagrams of nitrogen fertilizer distribution at two levels of total fertilizer and corresponding grain yields in kg/ha of three varieties, after two soil treatments. For explanation see Figure 65.

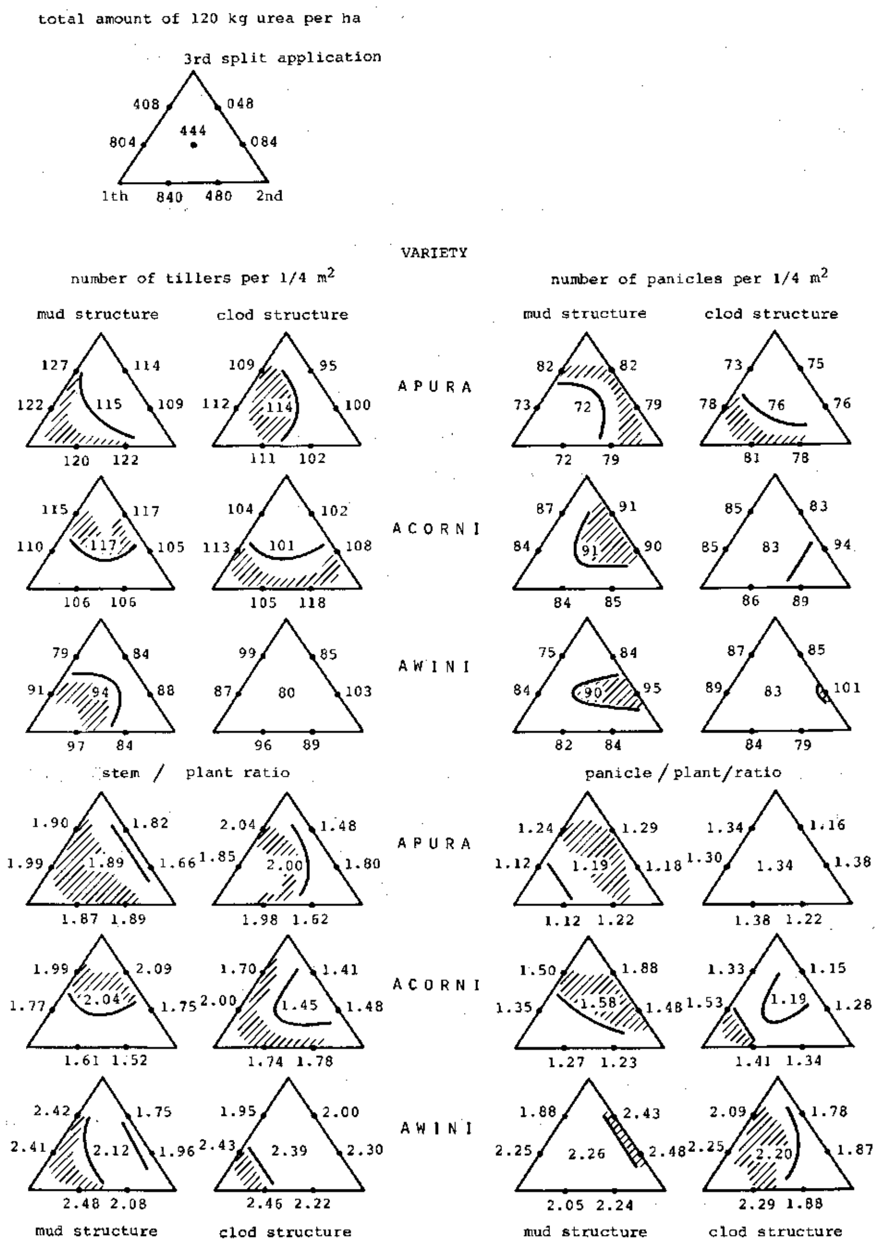
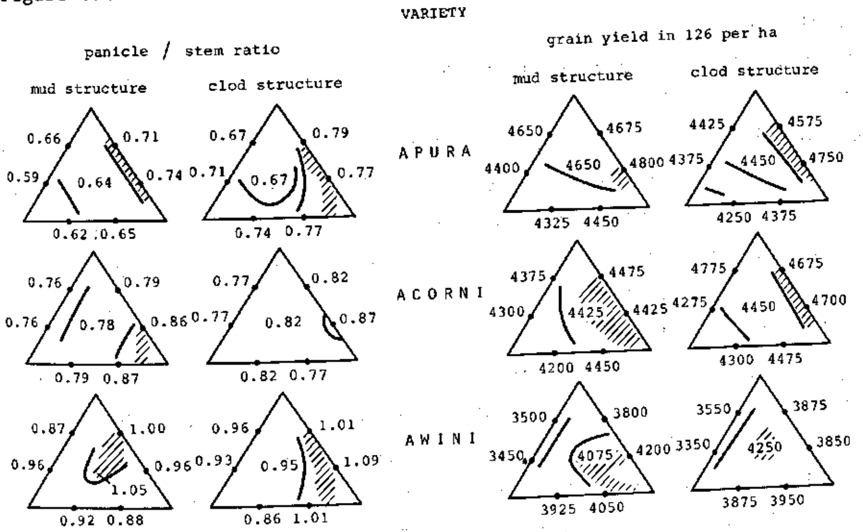


Figure 67. Diagrams of distribution of nitrogen fertilizer, using 120 kg urea per ha, and some plant parameters, for three varieties and two soil treatments. For explanation, see Figure 65.

Figure 67. Continuation



Only with Apura was this relation higher for clods than for mud. For all varieties, N applied at the first date decreased the relation for mud structure, and increased it for clods.

The panicle/tiller relation decreased in the same order as the panicle/plant relation. For all three varieties, the value was higher on clodded soil than on mud. The value decreased with early dressing and was increased most by an N dressing at the second and, to a lesser extent, the third date.

The role of the different soil treatments in the results will be discussed first. Sections 10.1 and 10.2 compared yields of grain harvested from soils subjected to tillage treatments with hardly any previous soil drying (wet and zero tillage) and with intense soil drying (dry and dry/wet tillage), but here in Section 10.3, two soil structures (clods and mud) are involved, for which the intensity of drying before tillage was the same. The level of soil ammonium is affected strongly by the intensity of soil drying before tillage (7.1). So in Trial 8, there was presumably a high level of exchangeable soil ammonium, somewhat more for mud than for clods (8.1). Mud leads to a high seedling establishment and rapid plant growth (8.2). In combination with a high ammonium level, these phenomena lead to a large number of tillers. In turn this number caused increased mutual shading and, in combination with a generally lower mineralization of soil organic nitrogen in the second part of the growing season (7.1), a low panicle/tiller relation.

These differences in soil structure influence grain yields of Apura and Acorni (Table 73). The lower maximum yield of these varieties for mud resulted from the lower panicle/tiller relation of these varieties than of Awini, for a similar number of panicles.

The two main differences between varieties in response to soil treatment cannot be accounted for by the measured plant characteristics. These differences are: (1) the favourable influence of clod structure on grain yield of Apura and Acorni, in contrast to Awini; (2) the favourable influence of supplying all fertilizer at the second date on grain yield of Acorni and Awini for the lower level of fertilizer.

This finding seems to be associated with a common genetic origin of the varieties Apura and Acorni, in spite of differences in their growth period. The common origin manifests itself in slow initial growth, erect leaves, and long tillers. In comparison with Awini, the other two varieties have more tillers, similar numbers of panicles and, hence, a lower panicle/tiller relation. Grain yields in fertilizer trials (11.2) support the view that on mud Awini responds entirely differently from Apura and Acorni. Presumably, the Asian progenitors of Awini possess rooting characteristics more adapted to mud.

The favourable response of Awini and Acorni to a large dressing at panicle differentiation for the low urea level (120 kg/ha) may be related to their short growth period and low production of straw. The absence of a vegetative lag phase may account for the favourable response to N in the middle of the growth period. The low straw production enables a proper level of N to be obtained in the shoots with a low supply of soil and fertilizer N. At 180 kg urea per ha, the number of variations in N distribution was too small to allow further conclusions to be drawn.

10.4 METHOD OF UREA APPLICATION

The influence of the form in which fertilizer nitrogen is applied to rice was investigated by ten Have (1967). In his trials only one tillage treatment was employed (dry/wet tillage). He found that higher yields were obtained when urea was applied as pellets to a drained surface in the middle of a four-day drainage period than when applied to continuously flooded fields.

His results were reconsidered in Field Trial 5, conducted to evaluate differences between tillage treatments (3.3). In Trial 5, urea was applied as: (1) a solution to the leaves; (2) pellets to a drained surface, in the middle of a four-day drainage period; (3) pellets to a continuously flooded soil;

(4) pellets to a newly flooded soil after a four-dav surface-drainage period. Results for soil-ammonium were discussed in Section 9.2.

Grain yields are given in Table 74. Unfavourable weather prevented implementation of the whole trial; hence, only average data are given. The general level of yield was low because of a slow start of growth.

Table 74 shows an interaction between tillage and water management. In the absence of urea, wet tillage resulted in lower yields on continuously flooded fields, and in higher yields on surface-drained fields than dry tillage. With urea, dry tillage yielded more than wet tillage, unless urea was applied in water after 4 days of surface drainage.

With surface drainage around dates of urea application, highest yields were obtained if the urea was applied to the drained surface, for both wet and dry tillage. With continuously flooded fields, highest yields are obtained with 100 kg urea/ha applied on leaves and with 160 kg urea/ha, when applied in water. Foliar application was efficient at the low level (50 kg per ha per dressing). However, at a high level (80 kg urea per ha per dressing) the concentration of the applied solution presumably suppressed growth and slight burning was observed.

Table 74. Influence of the way of applying urea at 100 or 160 kg/ha on grain yields (kg/ha) as affected by tillage and surface drainage

Surface drainage	Tillage	Yields (kg/ha)						
		No urea	To drained surface		To flooded surface*		To leaves	
			100 (kg/ha)	160 (kg/ha)	100 (kg/ha)	160 (kg/ha)	100 (kg/ha)	160 (kg/ha)
without	wet	1870			2475	2775	2745	2355
	dry	2620			3200	3475	3380	3335
with	wet	3040	3325	3675	3175	3410	2820	
	dry	2360	3600	4075	2840	3225	3090	

*"To flooded surface" refers to applying N one day after a 4-day drainage period, if surface drainage is included

1. Grain yield is a function of the number of panicles, of the number of grains per panicle, and of grain weight. The number of panicles is determined by the number of tillers and by the percentage of panicle-bearing tillers. Only in the zero tillage plot of one trial did the number of tillers limit grain yield. In it, many pre-soaked grains failed to germinate because of water shortage.

With dry/wet tillage there is a danger of excessive vegetative growth from a high percentage of germinating seed and rapid growth of the seedlings. This growth was found to be stimulated by a high level of soil NH_4 and resulted in many tillers per unit area. Dressings of N at tillering and at panicle initiation led to heavy mutual shading, which unfavourably influenced the photosynthesis-respiration ratio.

With dry tillage, in spite of the high level of NH_4 in soil, the hazard of excessive vegetative growth and of heavy mutual shading was low because of a low percentage of seeds germinating.

With wet tillage, a high germination percentage and rapid growth of seedlings gave rise to many tillers. Excessive vegetative growth and heavy mutual shading were, however, absent because of the low rate of mineralization of soil organic nitrogen. Already at tillering, a dressing of N was needed to maintain vegetative growth.

For the dry/wet treatment, the percentage of unfilled grains was high and was strongly affected by the pattern of fertilizer application. The percentage was lower for the wet treatment and very low for the dry treatment, and for these two treatments was little affected by pattern of fertilizer application.

Average grain weight was lower in the wet and dry/wet than in the dry treatment.

Through its influence on the percentage unfilled grains and average grain/ weight, mutual shading led to a higher straw/grain relation with dry/wet and wet tillage than with dry tillage.

In terms of grain production, the response of the variety Apura to variations in the quantity of fertilizer N applied was large for the tillage treatments dry/wet and dry and small for the treatment wet. In the treatment dry/wet, the response to variations in the distribution of fertilizer N over the various growth stages was larger than in the treatments dry and wet.

2. The effects of variations in the pattern of distribution of fertilizer N over three dressing dates at two total levels of N differed between the tillage treatments.
With a total of 120 kg urea per ha, dressing at tillering increased grain yield for the wet treatment, whereas for the remaining three treatments, a dressing then depressed yield. For all treatments, N applications at panicle initiation and differentiation promoted grain yields.
When a total of 180 kg urea was applied per ha, at the wet treatment highest yields were obtained when fertilizer N was equally divided over the applications at panicle initiation and differentiation, whereas for the remaining three treatments yields were highest when a third of the N was applied at panicle initiation and two-thirds at panicle differentiation.
3. Differences in grain yields of the varieties Awini, Acorni, and Apura were caused by variations in tillage, amount of N applied, and pattern of distribution of the N.
The varieties Apura and Acorni, which are crosses of varieties from Surinam and North America, yielded higher on a clod structure than on a mud structure, and responded favourably to a high degree of soil drying before flooding. With the variety Awini, a cross between Surinam and Asian varieties, yield was little affected by variations in tillage.
The short-season varieties Awini and Acorni (125 and 115 days, respectively) yielded most with low N dressings, whereas the long-season variety Apura (145 days) gave highest yields with high N dressings.
The short-season varieties responded most favourably to a single dressing of N at panicle differentiation, whereas the long-season variety yielded most when a third of the fertilizer N was applied at panicle initiation and two-thirds at panicle differentiation at least when the soil had had a chance to dry intensely before flooding.
4. In the absence of N fertilizer, periodic surface drainage raised yields after wet tillage, but lowered yield after the dry tillage. In combination with fertilizer N, periodic surface drainage increased grain yields. These increases were greater for the dry than for the wet treatment.
The effect of fertilizer N was highest when the N was applied half way through a four-day drainage period. In comparison with this method, application of N to soil reflooded after a drainage period, to a continuously flooded soil, or as a leaf spray was less effective.

11 Additional aspects

11.1 DIFFERENCES WITHIN THE FOUR TILLAGE TREATMENTS

The four soil treatments discussed in Chapters 5-10 do not correspond completely with commercial practice because of normal variations within a soil treatment. This section will discuss some of the effects of variations within the four tillage treatments.

11.1.1 The mud/paste effect

The consistency of puddled soils depends on their original properties (before flooding), the inundation period before puddling, and the puddling intensity. In potted soils consistency was varied from granulated to soft mud and stiff paste. By adding different amounts of water to the soil an intensely dried soil was wetted to 67% (paste) and to 80% water (mud) (Section 3.2, experiment 4). In the pots, rice was grown at humidities of 85 and 95%. Table 75 shows the dry weights of shoots after 60 days.

Growth was markedly better on the granulated soil, especially at lower humidity. Tensiometer values varied widely, but highest values did not differ between paste and mud for the same humidity. The lower humidity resulted in an increase in pF and was associated with a decrease in shoot weight, indicating a relation between transpiration and matric suction.

Soil drying to various moisture contents before flooding and puddling (Experiment 5, Section 3.2) affected the number of tillers on soft mud: the

Table 75. Influence of air humidity and soil structure on mean dry weight of shoots of plants 60 days old (after Koenigs & Scheltema, unpublished data)

	Dry weight of shoots (g/pot)			Highest tensiometer values
	clods	paste	mud	
Air humidity 85%	26	20	15	pF = 2.4
Air humidity 95%	25	21	19	2.1

Table 76. Influence of previous soil drying and of structure on the average numbers of tillers per pot on puddled soils

Soil structure	Previous soil drying down to		
	70%	40%	10%
mud	7.1	6.0	5.7
paste	6.4	6.1	6.7

stronger dried, the lower it was (Table 76). On stiff paste, the number of tillers was affected less and previous soil drying to 40% moisture gave the lowest number.

11.1.2 Redrying effect

Soil drying before flooding not only increases nitrogen mineralization after flooding (7.1) but also after rainfall, and subsequent redrying. Flooding again induces denitrification and loss of nitrate. These changes were studied in Pot Experiment 6 (3.2) for soils dried to 40% moisture and puddled afterwards, and for soils dried to 10% moisture after clod-making. Data refer to plants 34 days old; exchangeable soil ammonium was measured before planting (Table 77).

The *clods* were dried to 10% moisture, wetted to 60% and redried to 10%. Redrying only slightly decreased exchangeable ammonium but decreased nitrogen accumulation in the rice plant by 20%. The loss of mineralized nitrogen by denitrification was temporarily compensated by increased mineralization after flooding as a result of redrying. The total amount of ammonium produced during the 34 days was lower, as indicated by the decreased nitrogen accumulation in the rice plants.

Table 77. Effect of redrying soils wetted before flooding

Soil structure	Moisture changes before flooding (g/100g)	Exchangeable NH_4 before planting (mg/kg dry soil)	Nitrogen in shoots (mh/pot)	Number of tillers	Dry shoot weight (g/pot)
clods	70-10	5.39	176	34	7.77
	70-10-60-10	5.31	145	31	6.74
mud	70-40	2.99	75	22	4.15
	70-40-60-40	2.90	61	21	3.59

With *mud*, the unplowed soil was dried to 40%, wetted again to 60% and redried to 40%, whereafter it was puddled. Table 77 shows the same tendency as with redried clods, but the effect is much weaker.

In both treatments, wetting and redrying before flooding did not influence ammonium content before planting and only slightly influenced the number of tillers, but it distinctly changed shoot weight and nitrogen accumulation in the rice plants. This agrees with practical experience: after a very dry period, when the short rainy season fails, yields are extremely high.

11.1.3 Intensity of tillage

In the field, some variants in the three main tillage methods for dry, dry/wet and wet treatment are applied. They will be discussed separately (Section 3.3; Field Trial 4).

With *dry tillage*, the influence of tillage depth and of decreasing clod size in a uniform tillage layer of a certain depth was investigated.

Highest yields were with shallow plowing and large dressings of nitrogen (Table 78). With plowing to 20 cm, supplying more nitrogen was ineffective. Presumably deep tillage increases nitrogen mineralization, resulting in excessive vegetative growth, causing mutual shading, and resulting in lower grain yields.

Clods were reduced in size by plowing once, twice or three times to 12 cm depth. As Table 79 shows, plowing increased yields, but with 40 kg N/ha repetition had hardly any effect (whereas 90 kg/ha did); adding more nitrogen even tended to lower yield, perhaps for the same reason as in the previous experiment.

With *dry/wet tillage*, keeping plowing depth the same, various puddling intensities for seedbed preparation were obtained with beam or mudroll on drained and flooded fields (Table 80).

Table 78. Dry tillage: influence of tillage depth on grain yield (kg/ha) at two levels of nitrogen

Nitrogen fertilizer	Yields (kg/ha) according to tillage depth			
	0 cm	6 cm	12 cm	20 cm
40 kg/ha	2950	3875	3925	3825
90 kg/ha	3570	4400	4150	3825
Yield increase	+620	+575	+225	0

Table 79. Dry tillage: influence of plowing intensity on grain yield at two levels of nitrogen fertilizer

Nitrogen fertilizer	Yields (kg/ha) according to plowing intensity			
	0x	1x	2x	3x
40kg/ha	3175	4025	4200	4175
90 kg/ha	3900	3800	4050	4225
Yield increase	+425	-225	-150	+50

Table 80. Dry/wet tillage: influence of puddling intensity on grain yield at two nitrogen levels

Nitrogen fertilizer	Yield (kg/ha) according to puddling intensity			
	on drained field with	on flooded field with		
	1x beam	1x beam	1x mudroll	2x mudroll
40 kg/ha	4200	4150	4025	4050
90 kg/ha	4600	4350	4300	4150
Yield increase	+450	+200	+275	+100

Increased puddling intensity decreased grain yields. The decrease was larger with 90 kg N/ha than with 40 kg. Highest yields were obtained without puddling at seedbed preparation and 90 kg N. This is presumably due to an increased efficiency of the nitrogen.

In another experiment on four pairs of 72 ha fields beam and mudroll on flooded fields were compared (Table 81). The beam was more effective than the mudroll, and the difference was considerably larger for lower yields.

For *wet tillage*, some data were collected on the influence of puddling intensity on grain yield, by using weedcutter twice, four times or six times.

Puddling more than twice did not increase yield (Table 82). Application of 90 kg N/ha gave distinctly higher yield than 40 kg/ha for all puddling intensities.

Table 81. Dry/wet tillage: yield increase due to the use of the mudroll instead of the beam (calculated for pairs of 72 ha fertilized with urea)

	Yield (kg/ha) after beam treatment	Yield increase (kg/ha) of beam over mudroll treatment
Pair 1	4092	102
2	3968	167
3	3757	222
4	3742	458

Table 82. Wet tillage: influence of puddling intensity with weed cutter on grain yield at two levels of nitrogen

Nitrogen fertilizer	Yield (kg/ha) according to puddling intensity			
	0x	2x	4x	6x
40 kg/ha	3200	3375	3450	3325
90 kg/ha	3775	3750	3800	3875
Yield increase	+575	+375	+350	+550

11.2 DIFFERENCES IN REACTION OF ACORNI AND AWINI TO SOIL TILLAGE

The influence of tillage on grain yield could be influenced by variety. The Asian crosses represented by Awini seemed less influenced by puddling than the American ones represented by Acorni (10.3).

To test this, in a split field trial (3.3, no. 6) or variety x urea fertilization after wet and dry tillage, these varieties were compared. The yields of Awini were the same after dry and wet tillage (Table 83), Acorni yielded about as much as Awini after dry tillage, but much less after wet tillage. This outcome is in accordance with the results in 10.3, where Awini and Acorni were dealt with in separate trials.

One may be tempted to relate these differences to the tillage practices in Asia, where puddling is applied, and the Americas where it is not. Further investigations on this subject would be interesting.

11.3 INFLUENCE OF PHOSPHATE AND COPPER DRESSING

In the past, many fertilizer besides nitrogen have been tested in the Wageningen Polder, especially because of great damage associated with the occurrence of *Helminthosporium oryzae*. At first, it was supposed that the

Table 83. Influence of wet or dry tillage and amount of nitrogen fertilizer on grain yield (kg/ha), for two rice varieties

Urea applied (kg/ha)	Acorni		Awini	
	wet	dry	wet	dry
0- 0- 0	3350	3950	3600	3750
0-60-60	3900	4050	4500	4450
40-80-60	3950	4800	5000	4900

symptoms ('early yellowing') had something to do with deficiency of potassium, manganese or silicates, but later they proved to be a secondary phenomenon due to nitrogen deficiency as the application of a third urea dressing at panicle differentiation prevented them.

Adding phosphate and copper may, however, sometimes increase yields when nitrogen supply is optimum, as indicated by the following experiments.

In Pot Experiment 7 (3.2), phosphate (P-Olsen) was estimated two days before planting (Day-2) and 44 days after planting (Day 44) by the modified Olsen method (3.1). Initially these values were higher (Table 84) for dry than for wet tillage, but for dry tillage they decreased more than for wet tillage so that ultimately at Day 44 they were least for dry tillage. Independent of the phosphate level, with dry tillage 1.5 mg P per kg dry soil was taken up above that with wet tillage. Grain yields in Pot Experiment 7 were not significantly correlated with P-Olsen in soil before planting. Phosphate fertilizer increased yield on all soils ($P<0.01$), except Soil D, which had the highest P-Olsen. Grain yield was higher after dry tillage than wet tillage, except for Soil A, which had the lowest P-Olsen.

Soil P levels decreased after reclamation and cropping of rice, with which P was removed. P fertilizer will be needed in the future. Field trials indicated response to 200-600 kg/ha superphosphate in the Wageningen Polder, but results were rarely significant.

A positive correlation ($r=0,62$; $P<0,01$) exist between P-Olsen of the top 15 cm soil at the end of the season and grain yield of 40 m^2 with and without phosphate fertilizer. Indications exist of response of grain yield to *copper* fertilizer, 50 kg $CuSO_4$/ha. The yield response was more pronounced after puddling (dry/wet or wet) with a low urea level (120 kg/ha) than for unpuddled soils (dry or zero) and for a high urea level (180 kg/ha). Yield response differed between fields and seasons.

Table 84. P-Olsen (mg/kg dry soil) 2 days before (-2) and 44 days after (+44) planting, for two soil treatments after equal nitrogen dressing

Soil tillage	Soil A		Soil B		Soil C		Soil D	
	-2	+44	-2	+44	-2	+44	-2	+44
wet	0.41	0.08	0.85	0.54	1.70	1.36	2.35	1.93
dry	0.55	0.25	1.58	0.15	2.53	1.02	3.23	1.22

In Pot Experiment 7 copper fertilizer interacted with phosphate level of the soil. Copper increased yields only if phosphate was high in the soil (Soils C,D).

11.4 COST ASPECTS

The method of land preparation itself and its interaction with sowing, fertilizer dressing and water management are related to costs. It was outside the scope of this study to enter deeply into the field of interrelated costs, while the profit was difficult to establish under the local organization. Nevertheless some data may be supplied.

The costs of rice production per hectare are given in Table 85. The items dealt with in this study made up 42% of the total costs: land preparation, sowing, nitrogen dressing and water management.

Differences in costs of land preparation were small. The costs of field trenching as a standard operation was fixed. The costs of dry and wet tillage were about equal. The choice between the tillage treatments is not free, as dry plowing is only possible when weather conditions are favourable. Where possible, dry tillage is preferable since the organization of the work is more flexible and operations proceed with less interruptions or mishaps. These two aspects are difficult to express in money. Only for zero tillage were the costs of tillage absent, but the costs of chemical weed control before sowing were in the experimental conditions as high as tillage.

In stubble treatment, burning is almost standard practice. With wet tillage only loose straw can be burnt if the weather is wet. The rest is buried, so that stubble treatment costs less but puddling costs more.

Differences in costs of seedbed preparation were present. It was cheaper to use a beam than a mudroll because of its greater working width and lower maintenance costs. In addition the use of a beam on a dried soil in dry seedbed preparation gave higher grain yields.

Sowing costs may be reduced after dry/wet tillage or when vegetative growth at the start is intense, as with the variety Awini. With zero tillage, the seed rate should be increased as drying weather can be expected after sowing.

Omission of the first dressing at tillering has already become general practice and the resulting lower contributions of urea and plane to costs are incorporated in Table 85.

The present conditions in the Wageningen Polder involve high water costs;

Table 85. Production costs in Surinam guilders of rice (per hectare) in the Wageningen scheme. In 1970, Sf 1 = 0,55 dollar

	Sf	Sf	%
Labour		84	23
Land preparation stubble treatment	5		
preparation of tilled layer	37		
seedbed preparation	9		
field trenching	3	54	15
Sowing: Seed (90 kg/ha)	23		
broadcasting from plane	9	32	8
Nitrogen dressing urea 120 kg/ha	28		
broadcasting from plane	13	41	11
Pest control (weeds, insects): pesticides	29		
distribution from plane	14	43	11
Harvest		48	13
Water		30	8
Irrigation/drainage system		31	8
Other costs		13	3
Not calculated: land, interest, building, and overhead costs		--	--
	Total Sf	376	100

the fields have to be drained after sowing because of the inferior irrigation water (1.5) and irrigated again in a period of high pumping costs. The water costs of surface drainage period of 4 days for urea application in the middle of the growing season is low (Sf 3) and earned back by the more efficient use of the fertilizer.

Suggestions for lowering of the costs from this study are:

- for wet tillage, to reduce the number of puddling operations with the weed-cutter in the wet tilled layer preparation in combination with increased nitrogen dressing.
- for dry tillage, to reduce the depth of plowing in dry tilled layer preparation, using the beam for dry seedbed preparation combined with a slightly higher nitrogen dressing.
- for the Wageningen Polder, the use of clean irrigation water would reduce the cost of water and of weed control, favouring zero tillage.

SUMMARY CHAPTER 11

1. Within the mud structure, vegetative plant growth reacted to differences in structure in pot experiments. Mud with a low moisture content after puddling, resulted in a more intense growth than with a high moisture content after no previous soil drying. The reverse was true with previous soil drying

down to 10% moisture.

2. Redrying of the soil in the tillage period, after moistening an already dried soil, resulted in slightly less exchangeable ammonium in the soil before planting and less N accumulation in shoots and shoot dry weight at tillering. This redrying effect occurs with a level of soil drying previous to flooding of 10% as well as of 40% moisture, respectively, with clod structure and with unchanged soil mass before puddling.
3. The influence of intensity and depth of main tillage treatments on grain yields was studied:
   - dry tillage. The less deep (6 cm compared to 12 and 24 cm) and an average number of operations (2 compared to 1 and 3) yielded most.
   - dry/wet tillage. Increased intensity of puddling during seedbed preparation decreased yields.
   - wet tillage. The number of operations (2, 4, 6) with the weedcutter did not influence grain yield. The use of a beam instead of a mudroll during seedbed preparation increased grain yields.
4. The variety Awini (Asian origin) showed no lower grain yield after wet tillage, while the variety Acorni (American origin) and the SML variety Apura showed lower grain yields after wet tillage than after dry tillage.
5. The effect of phosphate and copper dressings on grain yield was not consistent. Grain yield was not related to P-Olsen in soil but the increase in grain yield due to phosphate dressing was related to P-Olsen values. Indications of copper deficiency with high phosphate level were found.
6. The costs of land preparation amounted to 13% of the total costs of rice production per hectare. Together with the interacting factors of seed, fertilizer, water, stubble treatment, and field trenching, the costs amount to 42% of the total.

   Differences in costs between types of tilled layer preparation were absent. At seedbed preparation, the use of a beam instead of a mudroll was profitable.

   The costs of water for surface drainage were small in comparison to the costs of fertilizer and its application.

12 Synthesis

Crop production usually requires measures to prepare the land for sowing or planting. Land preparation in the Wageningen Polder of Surinam involves treatment of the stubble remaining from the previous crop, tillage of the soil, and the construction of field trenches for proper water management.

The type of stubble treatment depends on weather in the intercrop period. When the weather is dry, most of the stubble can de bestroyed by burning. When burning is practicable, the stubble has to be crushed or cut in advance. In rainy weather, the stubble has to be buried by puddling.

Beside its use as for disposal of stubble, puddling can be a part of tillage operations to prepare a tilled layer and a seedbed.

Weather in the intercrop period determines the type of stubble treatment, and the nature and number of tillage operations. Thus, indirectly, the weather strongly influences the properties of the soil during the rice-growing season.

Tillage is distinguished into preparation of a tilled layer and of a seedbed. When dry plowing is practiced, the subsequent drying of the soil before flooding affects the soil moisture content thereafter, the bulk density, the hydration and dehydration characteristics, and, to a lesser extent, aggregate stability. In addition to changes in these physical properties mineralization of soil organic matter is enhanced.

Dry plowing is most effective in bringing about a mechanical fragmentation in the tilled layer; of subsoil fragments and of peat residues in the tilled layer. In comparison with wet tillage (puddling) and dry/wet tillage (combination of dry plowing and slight puddling thereafter), dry tillage allows greater permeability, both in the tilled layer and in the subsoil (10-50 cm). Zero tillage, however, leads to highest downward water transport. Permeability of the 50-100 cm zone is not influenced by reclamation or type of tillage.

The amounts of moisture released up to pF 2.7 after equilibrium are largest after puddling. The amounts released with time are, however, largest after dry plowing. Stability of the structural arrangement is lowest after wet tillage. Water extraction leads to compaction and is, therefore, partly irreversible. Pores collapse when suction is applied.

In the absence of soil loosening, zero tillage leads to compaction. Absence of tillage prevents the incorporation of plant residues in the top soil. The lack of easily decomposable organic matter in the soil results in lowered rates of nitrogen mineralization and in reduced iron contents in soil moisture. The latter is caused by a lack of energy source for anaerobic microorganisms that use trivalent iron as an electron acceptor thus reducing the iron to the soluble bivalent form. The organic residue left on the soil, when tillage is omitted, can prevent contact between seedling and soil water, thus increasing the risk of desiccation of the rice plants in an early stage. This risk is greater when drying weather prevails during seedling emergence.

Water movement in the soil is induced by the action of rice roots which withdrawn water from the soil. In a recently reclaimed swamp water levels inside piezometer tubes coincide with the floodwater level independently of the type of tillage. In a soil reclaimed 20 years ago, the distance between the two levels was largest with wet tillage, and increased during the growing season. Hydraulic potential tubes indicated the occurrence of overpressures in the soil and of gas in pore widenings that cause water transport to be blocked.

Downward water transport is impeded by low permeability and decreases in the order zero, dry, dry/wet and wet tillage. With dry/wet tillage, a hydraulic head is present for upward water transport from the 50-100 cm layer to the 10-50 cm layer, thus compensating for the gravity component. A shunt connection between the floodwater and the permeable 50-100 cm is presumed: with dry/wet and dry tillage for water transport, and with wet tillage for transmitting changes in floodwater depth.

The distribution and intensity of iron oxide accumulations at the surfaces of channels and planes are regulated by the pathway taken by oxygen in penetrating the soil, and by the iron content of the soil moisture. For all tillage treatments, oxygen penetrates the soil mainly through rice roots, and thus causes the formation of channel neoferrans, which are most intense with wet tillage and least with dry tillage. Oxygen penetrates the soil from the irrigation water and from the air in periods of surface drainage. With wet and dry/wet tillage, plane neoferrans are limited to the sedimented layer. Plane neoferrans are most intense with dry tillage. They occur along clod surfaces, and increase in thickness during the growing season because of lower iron contents in soil moisture at the start of the season and because of easier penetration of oxygen into the tilled layer.

The work discussed was prompted partially by the observation that in the Wageningen scheme the colour of the rice crop is influenced by the type of soil tillage. The thought arose that this influence would be an indirect one, in that the level of available soil ammonium would be affected by the type of soil tillage, and that in turn the colour of the rice crop would be a reflexion of the availability of soil ammonium. Early investigations failed to show that during the growth of a rice crop the level of soil ammonium was significantly influenced by the type of tillage before sowing. Also in pot experiments (Chapter 7), the level of soil ammonium was found to be only slightly influenced by the type of soil structure, although in pots the residual value was lower than in the field. More intense rooting in pots is likely to be the cause of these lower values.

With plastic cylinders in the field (Chapter 7), it was shown that the production of soil ammonium is strongly affected by variations in soil tillage. Much more soil organic nitrogen is mineralized after dry than after wet tilled layer preparation. Dry tilled layer preparation (dry plowing), however, is not always possible under weather conditions prevailing in north west Surinam, where intensity and distribution of rainfall may deviate widely from calculated mean values. When dry tillage is practiced, it brings the soil into a clodded condition in which further drying is possible after tillage. Such further drying stimulates the production of soil ammonium after flooding during the cropping season.

When, however, weather conditions prevent the soil from drying out properly, a wet tilled layer must be prepared (puddling). Puddling as such also promotes the mineralization of soil organic nitrogen, but it does not allow the soil to dry out to a level at which large additional amounts of soil ammonium become available for plant uptake.

The question can be raised whether the tillage operation itself or factors influenced by tillage promote the mineralization of soil organic matter. In upland dry-farming conditions, tillage is thought to expose new surfaces to the action of soil microorganisms. The direct and indirect effects of soil tillage on soil organic matter mineralization are hard to unravel, but in lowland rice culture, in particular the occurrence of intense soil drying, facilitated by dry plowing, enhances the mineralization of soil organic nitrogen. The results of Chapter 7 indicate that in the absence of such a drying process, as with wet tillage, zero tillage, and in a flooded swamp soil, the production of soil ammonium lags far behind that found where tillage or drainage enabled the soil to dry out intensely.

When after intense soil drying, the soil is brought in a mud by puddling, conditions remain favourable for the production of soil ammonium. With complete puddling after dry plowing in pot experiments the ammonium production is increased. In field conditions a slight puddling in seedbed preparation after dry plowing (dry/wet) tillage results in slightly lower ammonium production.

It is well known that young rice seedlings are particularly sensitive to drought. Any positional, physical or chemical factor hampering the availability of water to rice seedlings, has to be avoided. The rough surface of a dry-tilled soil allows the upper portions of clods to dry out more than the lower portions. Any seeds that happen to lodge on the upper portions of clods during sowing, run the risk of desiccation during establishment.

Thus, dry tillage has the advantage of leaving the topsoil in a position in which a drying process continuing after tillage may raise the level of availability of soil nitrogen after flooding by increased mineralization of soil organic nitrogen. In a season with drying weather during the germination process, this advantage may be only slightly offset by poor seedling establishment.

With zero tillage the combination of a poor seedling establishment and a low soil ammonium level is unfavourable and results in low grain yields. If this situation arises, the amount of soil ammonium available to plants may become useless because of an insufficient number of plants per unit area.

Under normal circumstances, the stimulatory effect of tillage on mineralization of soil organic nitrogen ensures adequate N nutrition of the rice plants up to tillering. Exchangeable soil ammonium present at sowing is readily available to the rice plants, but after tillering little additional ammonium is made available by the soil in the absence of dry plowing and subsequent drying of the soil (wet and zero tillage). Rice in pots responds favourably to a basal dressing of fertilizer N, but the recovery of this fertilizer N is poorer than of soil ammonium available at sowing, although intense drying of soil before flooding has a positive effect on recovery of fertilizer N. In field experiments a basal dressing of fertilizer N did not increase grain yields.

There are indications that after intense soil drying in the field facilitated by dry tillage, the recovery of fertilizer N is somewhat more than after wet tillage. It also appeared that after dry tillage, rice roots were able to absorb nitrogen from a greater depth than after wet tillage.

The most important factor contributing to the recovery of fertilizer N, however, was the availability of soil ammonium. Availability was lowest after zero tillage and, consequently, the highest percentage recovery of fertilizer N was found with this treatment. Soil tillage stimulates mineralization of soil organic nitrogen in several ways. Absence of tillage, therefore, can be expected to result in low levels of mineralization and in high utilization of fertilizer N. With wet tillage, however, low mineralization coincided with a low recovery of fertilizer N in the shoots. This is related to the sedimented layer and unfavourable conditions with wet tillage.

Even more so than farming on aerobic soils, lowland rice on anaerobic soils is faced with hazards of nitrogen being lost from soil without having functioned as a plant nutrient.

Nitrogen may be lost from flooded soils by deep percolation and denitrification. Because of the impermeability of the heavy subsoils in the Wageningen Polder, deep percolation is no serious threat to efficient use of fertilizer N. The danger of denitrification, however, is always present, and cultural practices to lower the risk of denitrification are much needed. With wet tillage the presence of the sedimented layer at the surface will promote the nitrification and subsequent risk of denitrification.

The results of the present experiments show that foliar application of nitrogen offers no great advantages over more conventional methods of applying fertilizer. The loss of applied fertilizer with wet tillage can be overcome by foliar application. This occurs only at a low dressing rate and in the absence of surface drainage. This reaction shows interference of puddled soil with fertilizer recovery. In practice with larger amounts of fertilizer and with surface drainage urea dressing with pellets to a drained surface is more efficient. In theory, the practice of applying urea to the soil on the second or third day of a four-day surface drainage introduces the risk of urea nitrogen being converted to ammonium nitrogen and, subsequently, to nitrate nitrogen before reflooding. The results obtained show, however, that this method of application leads to higher recovery rates than application of urea to a flooded soil shortly after surface drainage or without any drainage period. Hence, nitrification of ammonium is of minor importance during the short period between application of urea to a drained surface and reflooding of the soil. The urea N or ammonium N, present on the soil surface, is probably transported downward by irrigation water entering the soil. Such transport may protect the nitrogen from being nitrified in the upper oxidized layer of the soil, whereas without the occurrence of downward water movement, nitrogen may be converted to nitrate and may be volatilized by denitrification. This process can be expected to affect more nitrogen early in the cropping season, when the primary root system does not explore the upper layer of the soil, whereas in the latter part of the cropping season, the more superficially active secondary root system may intercept part of the nitrate nitrogen before it is denitrified.

Translocation of fertilizer nitrogen to deeper layers is facilitated by dry tillage, resulting in better utilization of fertilizer N. Conversely, the presence of puddles during the period of surface drainage hampers such translocation of fertilizer N, and leads to low recovery. The clodded soil surface after dry tillage, in absence of a sedimented layer, promotes the penetration of irrigation water into the soil. Rainy weather during this period prevents the soil from drying out, obstructs the penetration of newly applied irrigation water, and, consequently, lowers the efficiency of fertilizer nitrogen.

Obviously, any body applying fertilizer nitrogen hopes for a high recovery of N applied. Nevertheless, the present experiments showed that, under certain conditions, high recovery of fertilizer N does not result in high grain yields. Basal applications in field conditions had no response on grain yield. After a combination of dry plowing and slight puddling (dry/wet tillage), soil ammonium supply may be too large. When seedling establishment is high, a high rate of mineralization of soil organic nitrogen may ensure an adequate supply of nitrogen even to the relatively high number of plants per unit area. The large available amounts of soil ammonium and any additional nitrogen applied may be absorbed by the plants, but it may result in a rate of tillering too high to ensure that adequate light is available for each individual tiller. Consequently, many tillers remain barren, the tillers receiving an inadequate share of the available light exert an unfavourable influence on the photosynthesis-respiration ratio, and die prematurely. Thus, a high utilization of fertilizer nitrogen may lead to suboptimal grain yields.

Excessive plant density may be avoided by decreasing the seed rate, after dry/wet tillage, when weather conditions are favourable for a seedling establishment. Seedling growth is slower at dry tillage, resulting in a low dry matter production at tillering, never resulting in an excessive vegetative growth even at higher seed rates. Under such conditions excessive tillering is avoided, and the crop may respond well, in terms of grain yield, to fertilizer nitrogen applied after tillering, at panicle initiation.

When weather conditions are unfavourable for dry plowing and, consequently, wet tillage has to be practiced, mineralization of soil organic nitrogen will be low, and the crop will respond favourably to an early dressing of fertilizer N at tillering.

It is difficult to make any general statements on cultural practices optimal for grain production, that apply to all varieties used in the Wageningen

Polder. Some varieties, like Apura and Acorni, appear to be adapted more to cultural practices of dry plowing favoured in the western hemisphere, whereas the variety Awini, with its partially Asiatic background, reflects an adaptation to mud structure, commonly practiced in South East Asia.

Summary

In the Wageningen Polder in Surinam land preparation involves stubble treatment, tillage and field trenching. The type of land preparation is regulated mainly by the weather, determining the drying of the stubble and the soil, influencing the possibilities for stubble treatment and tillage.

The stubble is buried by puddling if not sufficiently dried for burning. Burning needs a preceding crushing or cutting of the stubble. Tillage involves preparation of the tilled layer and of the seedbed. Both may be either on dry surface drained soil (if weather conditions favour the drying of the soil needed for plowing -- dry tillage), or else on a flooded soil (wet tillage). A combination of dry preparation of the tilled layer and wet preparation of the seedbed is called dry/wet tillage; absence of both -- zero tillage.

The type of tillage influences the soil in the tilled layer by:

1. Drying of the soil before flooding
2. Mechanical forces during tillage
3. Incorporation of organic matter
4. Soil structure

1. The drying of the soil in the period of tillage before flooding below the shrinkage limit is achieved only after dry plowing. This drying does not influence morphological characteristics (Chapter 5). Physically the drying affects soil moisture after flooding, bulk density, hydration curves and only slightly affects the stability of soil aggregates (6.1; 6.2; 6.3; 6.8). Chemically drying increases mineralization of organic matter in the soil, measured as exchangeable ammonium after flooding by a factor of 2.5. This increase is high (15 kg N ha^{-1} 30 $days^{-1}$) in the first 1½ month and lower (5 kg N ha^{-1} 30 $days^{-1}$) thereafter (7.1). Wetting of the soil after drying and subsequent redrying before flooding reduces this increase (11.1.2).
2. The mechanical influence of the forces during tillage is absent with zero tillage. Puddling in wet tillage largely destroys soil structure, resulting in a solid mass. Plowing results in clods, with continued coherence within them and cavities between, which are larger after dry tillage and partly

packed or filled after dry/wet tillage (5.2).

A sedimented layer occurs in the puddled treatments by sedimentation of clay and organic matter particles brought into suspension at puddling at the surface and also between the clods inside the tilled layer after dry/wet tillage. Residual sedimented layers are most frequent after dry/wet tillage as they are incorporated during plowing in the tilled layer, and less frequent after wet tillage by almost complete destruction in the next puddling operation. Residuals occur still after three seasons of dry or zero tillage where formation is absent (5.4).

Mechanical fragmentation of subsoil fragments and peat residues in the tilled layer is most intense with dry plowing (5.6). Puddling breaks up organic matter particles most by a combination of mechanical and microbial influences (5.5).

Compaction occurs with zero tillage in absence of soil loosening and with soil traffic at harvest and stubble treatment. Wet seedbed preparation after clod formation results in slight compaction (6.2; 6.3). Dry plowing reduces downward water transport as compared with zero tillage, presuming a compaction or kneading below the tilled layer as observed from piezometer tube data (6.6.2.1).

3. The incorporation of easily decomposable organic matter increases nitrogen mineralization as measured by soil ammonium in a tilled soil over that in a swamp soil or zero-tilled soil. Complete puddling in pot experiments results in slightly higher soil ammonium contents than clod making at the same level of soil drying before flooding (factor 1.1-1.4) (7.1.3). Field puddling in seedbed preparation after dry plowing (dry/wet tillage) results in equal or slightly lower ammonium contents than with dry tillage (7.1.2). Iron contents in the soil moisture are lower throughout the growing season in the absence of this incorporation at zero tillage and below the tilled layer, by less microbial activity (7.2).
4. The soil structure achieved with the various tillage treatments differs and influences the soil moisture contents (6.1). The amounts of moisture released up to pF 2.7 after equilibrium (dehydration curves) are largest after puddling (6.3). The amounts released with time (soil moisture extraction procedure) are largest after dry plowing (6.4).

   Water permeability in the tilled layer was too low to be measured with wet tillage and over 10 m/day after dry tillage. Water permeability in the 10-50 cm zone was strongly reduced after 20 years of rice cultivation on former swamp soils. Differences still occurred within the tillage treatments:

wet 0-3 mm/day, dry/wet 4-15 mm/dav, dry 8-70 mm/day. Water permeability of the 50-100 cm zone is not influenced bv reclamation or tillage (0.1-2 m/day) (6.5). Tillage is general and puddling superficial decreased permeability to water by destroying open channels or by filling up voids with mud by puddling.

Stability of the structural arrangement is lowest after wet tillage, where water extraction is partly irreversible and accompanied by compaction (6.1), pores collapse by applying suction at soil moisture extraction (6.4) and a larger part of the soil mass went into suspension (6.8).

The conductivity of the soil moisture increases with depth and in the order dry, dry/wet, zero and wet tillage, because of the dependence on dilution of soil moisture with floodwater (6.7).

The soil structural arrangement influences:

1. Seedling establishment and seedling growth
2. Fate of applied urea
3. Effect of surface drainage on ammonium content in the soil
4. Water movement
5. Accumulation of iron oxydes

1. The establishment of seedlings and the growth thereafter on surface drained fields is mainly dependent on the availability of water. Due to local conditions, of muddy irrigation water infested with snails and water weevils, the fields are drained for two weeks after sowing (1.5). With a puddled seedbed (wet and dry/wet tillage), water availability is not limiting. Water availability is low in drying weather for seedlings on patches of residual stubble (all treatments), on dried tops of clods (dry tillage) and on the layer of partly burnt stubble residues (zero tillage). Seedling establishment and seedling growth are larger with dry/wet and wet tillage, then with dry tillage and varies largely with zero tillage according to the weather. The lead of dry/wet and wet tillage as measured in dry matter production slows down after reflooding, but it still present at tillering (8.2.1).
2. The applied urea is hydrolysed and transformed to ammonium most rapidly in combination with a period of surface drainage and with wet tillage. The ammonium formed disappears within a few days with uptake by the rice plant or nitrification. Only with application of urea to a surface drained soil is the ammonium transported after flooding with water entering the soil to below the oxidized zone. There the ammonium is protected against nitrification and subsequent denitrification. The downward transport of urea and ammonium is more intense with dry tillage than with wet tillage, due to sur-

face conditions (9.2).

3. The effect of surface drainage on ammonium content in the soil. A period of surface drainage for 4 days allows oxidation of ammonium in the soil to nitrate. The oxidation is limited with wet tillage by the sedimented layer, while with dry tillage it is favoured by the large soil surface area including the clod surfaces along the cavities connected with the surface. The nitrate is partly taken up by the rice plants, partly denitrified after reflooding. The drying of soil during the surface drainage induces an increased nitrogen mineralization after reflooding. The soil ammonium content decreases more with wet tillage than with dry tillage after a period of surface drainage, but nitrogen accumulation in the rice plant is larger with wet than with dry tillage in the absence of nitrogen fertilizer. The loss due to denitrification is assumed to be largest with dry tillage. The increase in mineralization due to drying is assumed to be largest with wet tillage,as a larger part of easily decomposable organic matter is still available (9.2).
4. Water movement in the soil is induced by extraction from the soil by rice roots. Calculated values of matric suction according to a presented model showed values of 60 cm water height at 50 cm depth. Water levels inside piezometer tubes coincide with the floodwater level in recently reclaimed swamp soils and with zero tillage in a soil reclaimed for 20 years. With wet tillage, the distance between the two levels increased during the growing season. The distance between the levels increased in the order zero, dry, dry/wet and wet tillage. Piezometer tubes and tensiometers indicated matric suctions of 20 cm water height at 20 cm depth which agree with the calculated data. Below this depth the calculated values increase while the measured ones decrease. This discrepance is assumed to be due to a non continues transpiration of the rice plants and a non uniform water extraction over the rooted zone. Hydraulic potential tubes indicated the occurrence of overpressures in the soil and gas in pore widenings, blocking water transport (6.6).

   The downward water transport is hampered by the low permeability and decreases in the order zero, dry, dry/wet and wet tillage. With dry/wet tillage, a hydraulic head is present for upward transport from the 50-100 cm layer to the 10-50 cm layer, compensating for the gravity component. A shunt connection between the floodwater and the permeable 50-100 cm zone is presumed: with dry/wet and dry tillage for water transport and with wet tillage for transmitting changes in floodwater depth (6.6).
5. The occurrence of iron oxide accumulations on the surfaces of channels and

planes are regulated by the pathways through which oxygen penetrates the soil and by iron contents in the soil moisture. Oxygen penetrates the soil through rice roots at all treatments causing channel neoferrans, which are most intense with wet tillage and least with dry tillage. Oxygen penetrates the soil surface from the irrigation water and from the air in periods of surface drainage. Plane neoferrans are limited to the sedimented layer with wet and dry/wet tillage. With dry tillage, plane neoferrans are most intense. They occur along clod surfaces, increasing in thickness during the growing season, because of the lower iron contents in the soil moisture at the start of the season and the easier penetration of oxygen into the tilled layer (5.4).

Nitrogen mineralization influences plant growth largely and was:

1. Studied systematically in pots
2. Evaluated in practical conditions in the field

1. In potted soils, soil structure (clod versus mud) and previous soil drying were studied factorial with planted rice. Previous soil drying largely affected nitrogen accumulation in rice shoots up to tillering. Soil structure affected accumulation only slightly. After tillering, nitrogen accumulation was regulated only by topdressings. Previous soil drying and soil structure affected dry matter production during the whole growing season (8.1.1).

   The effect of previous soil drying with a 70-100% recovery of soil ammonium in the rice shoots, can be compensated with preplanting urea dressing with a 33% recovery (8.1.1.3). The recovery of split topdressings increased with previous soil drying (from 45 to 72% and with time from 42 to 66%) (8.1.1.2).

   The level of soil ammonium at tillering and thereafter was low and constant compared to higher and variable values with time in the field, indicating a far more intense extraction of ammonium by the rice roots in potted soils (7.1).
2. In the field, nitrogen accumulation at tillering was dependent on dry matter production and on the nitrogen content of the shoots. The dry matter production was large after wet seedbed preparation (wet and dry/wet tillage). The nitrogen content was related to the soil ammonium content and high after intense previous soil drying (dry and dry/wet tillage). The combination of both resulted in an increase in accumulated nitrogen in the order zero, dry, wet and dry/wet tillage (8.2.2).

   Nitrogen accumulation after tillering was considerably higher after intense previous soil drying up to panicle initiation. Thereafter the part of soil ammonium in plant nitrogen accumulation was much lower for all tillage treatments (9.1.2).

The exchangeable soil ammonium in the soil at the same time was equal for all tillage treatments. Soil ammonium content was estimated from extraction intensity of the rice roots, by which all ammonium is extracted above a certain level which varies during the growing season (7.1.2).

Plant growth is influenced by interaction of soil tillage, seed rate and nitrogen dressing through:

1. Canopy density
2. Nitrogen uptake pattern of the rice plant
3. Recovery of fertilizer nitrogen in the rice plant
4. Varietal differences

1. Canopy density determines the production of assimilates by photosynthesis in relation to consumption by respiration. A dense canopy causes high mutual shading, resulting in a low net assimilation and losses of nitrogen by dying of shaded leaves. Canopy density is regulated by tillering intensity and dry matter production. The number of tillers limits grain production by producing too few panicles at zero tillage and low seedrates, because of low seedling establishment a slow seedling growth and a small amount of nitrogen accumulated at tillering. The number of tillers limits grain production by causing intense mutual shading at dry/wet tillage at high seed rates because of high seedling establishment, rapid seedling growth, large amount of nitrogen accumulated at tillering and large supply of soil ammonium after tillering up to panicle initiation, resulting in a low percentage productive tillers.

   With dry tillage and with wet tillage, either the seedling establishment and seedling growth or the soil ammonium supply is large, while the other is small. This ensures sufficient tillers without danger of detrimental mutual shading. With zero tillage seedling establishment and growth and soil ammonium supply are low, which causes the risk of a too open canopy, limiting grain yields.
2. Nitrogen uptake pattern of the rice plant throughout the season. Accumulation of nitrogen starts high for dry/wet tillage and continuous at a high level thereafter. With dry tillage, the accumulation of nitrogen is low up to tillering but stays even with dry/wet tillage at panicle initiation. Accumulation at wet tillage lags behind after tillering; that of zero tillage is always lowest. This pattern of nitrogen accumulation is associated with a high average grain weight and a low percentage empty husks at dry tillage. With dry/wet tillage, average grain weight is low and the percentage of empty husks is high. With wet tillage, the pattern is intermediate with a low

average grain weight, and a low percentage of empty husks. The lower grain yields at wet tillage are presumed to be related to a lower number of grains per panicle.

3. Recovery of fertilizer nitrogen in the rice plant. With wet tillage the recovery of the applied nitrogen is low (9.1.2), due to rapid transformation of the urea to ammonium and nitrate and less storage of ammonium below the oxidized zone after reflooding (9.2). The dressings cause a substantial lowering of the uptake of soil nitrogen, presuming a concentration of the rooting activity in the upper centimetres of soil. The recovery is high from dressings at tillering and panicle initiation, when soil nitrogen supply is almost absent (9.1.2). Highest grain yields correspond to this pattern with the amphasis on early dressings: at a low urea level, it should be evenly distributed over tillering, panicle initiation and panicle differentiation; at a high urea level half should be given at panicle initiation and half at panicle differentiation (10.2).

   With dry/wet tillage, the recovery of the applied nitrogen at tillering or in combination with a dressing at tillering is low, while grain yields are decreased. This effect is due to the large amount of nitrogen accumulated at tillering in the shoots (8.2.2). The recovery is intermediate between wet and dry tillage. The dressings does not influences the uptake of soil nitrogen by the rice plant (9.1.2). The recovery is large in the absence of the dressing at panicle initiation, grain yields are,however, largest with a third at panicle initiation and two thirds at panicle differentiation (10.2).

   With dry tillage, the recovery of the first dressing in the season at tillering or at panicle initiation shows a low recovery shortly thereafter, but a large one at the end of the season. This effect suggests temporarily immobilization of applied nitrogen, resulting in high grain yields. The recovery is high, because of a lower transformation of urea and smaller losses from denitrification by storage of the ammonium in the reduced part of the tilled layer. High recoveries were obtained with dressings at panicle initiation, panicle differentiation and flowering (9.1.2). Grain yields corresponded with recoveries, except for the dressing at flowering (10.2). With zero tillage, the recovery is larger than with the other treatments. The fate of the applied urea was not studied here. The high recovery is associated with low soil ammonium supply and the absence of a sedimented layer presumes storage of added urea as ammonium in the reduced layer. High recoveries are obtained with dressings at tillering and panicle initiation, early in the season, when the amounts of nitrogen accumulated are minimum (9.1.2). Highest grain yields at a low urea level are obtained with dressings at tillering, panicle initiation and panicle differentiation; highest grain yields at a high urea level with dressings at panicle initiation and panicle differentiation (10.2).

4. Varietal differences occur in the reaction of plant growth. The Surinam SML late-maturing variety Apura and the early maturing variety Acorni (American cross) accumulate less nitrogen at tillering after wet tillage than after dry tillage, which is in accordance with the soil ammonium contents, and produce lower grain yields. The early maturing variety Awini (Asian cross) accumulates equal amounts of nitrogen at tillering after dry and wet tillage and after wet tillage yields as much as or more than after dry tillage. It is tempting to presume characteristics more adapted to puddled soil in Awini, inherited from its Asian progenitors (10.3; 11.2).

Samenvatting

Modderen of droog ploegen bij de natte rijstverbouw in Suriname: beinvloeding van bodem en plant, en interacties met bevloeing en stikstofbemesting.

Onderwerp van onderzoek was de grondbewerking bij de verbouw van rijst op zware klei in de polder 'Wageningen", gelegen in de jonge kustvlakte van Suriname. Enkele praktische problemen, en de ondoorzichtigheid van de invloed van de bodembehandeling op de korrelopbrengst vormden de aanleiding.

Na een beschouwing over de funktie van het modderen bij de grondbewerking, de lokale omstandigheden en de methode van rijstverbouw, werd een overzicht van de literatuur gegeven.

Bij de grondbewerking werd onderscheid gemaakt tussen die voor het maken van de bouwvoor en die van het zaaibed op droge en op onder water staande velden. Onderzocht werden de bewerkingen 'nat' (uitsluitend modderen), 'droog/nat' (na drogen licht modderen), 'droog' (zowel van bouwvoor als van zaaibed) en 'onbehandeld'. De uitvoering van deze bewerkingen en de invloed van de stoppelbewerking, de weersomstandigheden en andere faktoren werd besproken.

De invloed van de bewerking op de grond werd onderzocht langs morfologische weg (aan de hand van slijpplaten), langs chemische weg (ammonium-gehalten, samenstelling van het bodemvocht) en langs fysische weg (vochtgehalte, volumegewicht, dehydratie-curven, vochtonttrekking, doorlatendheid, vochtpotentialen en stabiliteit van de struktuur).

De verschillen in de struktuur van de grond veroorzaakt door de grondbewerking, beinvloeden:

1. Het aanslaan van het voorgekiemde zaad op drooggezette grond en de daarop volgende groei van de zaailingen (een grotere hoeveelheid beschikbaar water na modderen bevordert beide);
2. De stikstofverliezen in de grond bij droogzetting door denitrificatie (die hoger bleken te zijn bij een oppervlak van kluiten dan bij een oppervlak dat bedekt was met een na modderen gesedimenteerd laagje);
3. Het effekt van ureumtoediening op drooggezette grond (na het weer onder water zetten dringt ammonium de grond binnen en wordt getransporteerd tot

beneden de geoxydeerde zone, en wel in sterkere mate bij de bewerking 'droog' dan bij 'nat');

4. De waterbeweging vanuit het bevloeiingswater in de grond ter aanvulling van de door de wortels onttrokken water (die afneemt in de volgorde 'onbehandeld' - 'droog' - 'droog/nat' - 'nat');

5. De ophoping van ijzeroxide-neerslag (bepaald door de hoeveelheden ijzer die in de bodemoplossing aanwezig zijn en de plaatsen waar zuurstof de grond binnen dringt).

De stikstofmineralisatie in de grond bleek sterk te worden bevorderd door een intensieve uitdroging van de grond vóór het onder water zetten. Intensieve uitdroging komt in veldomstandigheden alleen voor na het ploegen. In potproeven leverde modderen via de kluitstruktuur een kleine bijdrage tot de stikstofmineralisatie, in veldproeven geen. In potproeven bleek de gemineraliseerde stikstof in de grond de groei van de rijstplant in sterke mate te beinvloeden tot de uitstoelingsfase, in veldproeven tot de pluimaanleg. In het veld nam de beschikbare hoeveelheid ammonium in de grond toe in de volgorde van de bewerkingen 'onbehandeld' - 'nat' - 'droog/nat' - 'droog'.

Groei en korrelopbrengst werden beinvloed door een interactie tussen grondbewerking, zaaidichtheid, totale stikstofgift en de verdeling daarvan, en ras. Daarbij kon onderscheid gemaakt worden tussen de volgende aspekten.

1. Dichtheid van het bladerdek. Bij een dicht dek bestaat gevaar voor onderlinge beschaduwing, wat bij de bewerking 'droog/nat' leidt tot een hoog percentage voze korrels, een laag percentage produktieve stengels en een hoge stro/korrelverhouding, bij de bewerking 'onbehandeld' tot een gering aantal pluimen per oppervlakte-eenheid.

2. Verloop van de stikstofopname. De beschikbaarheid van stikstof in de grond is bij de bewerkte gronden voldoende tot de uitstoelingsfase; bij de grondbewerking 'onbehandeld' is ze laag. Na de uitstoeling is de stikstofvoorziening laag bij 'nat'; bij 'droog/nat' en 'droog' gaat ze bij het ras Apura bevredigend door tot de pluimaanleg, maar daarna is ze te verwaarlozen. Extra stikstoftoediening is bij 'nat' en 'onbehandeld' nodig bij de uitstoeling, of als een grotere gift bij de pluimaanleg (beide in kombinatie met een gift bij pluimdifferentiatie). Bij de bewerking 'droog/nat' en 'droog' levert een hoge gift bij pluimdifferentiatie een hoge korrelopbrengst, in kombinatie met een gelijke of lagere gift bij de pluimaanleg.

3. Toename van stikstof in de plant als gevolg van bemesting. Deze toename is laag bij de bewerking 'nat'; bij 'droog/nat' is ze sterk afhankelijk van de verdeling van de mestgift; bij 'droog' is ze hoog en bij'onbehandeld'zeer hoog.

4. De reaktie in groei en korrelopbrengst op de grondbewerking is verder afhankelijk van het gebruikte rijstras.

Een ondiepe bouwvoorvorming uitgevoerd in een klein aantal gangen en een zaaibedvorming met gebruik van de balk is het meest rendabel. De uitvoering van de grondbewerkingen 'droog' en 'droog/nat' is afhankelijk van het weer; ze verdienen de voorkeur omdat ze eenvoudig zijn en een hoge opbrengst geven. De bewerking 'droog/nat' wordt het meest toegepast, maar ze geeft de kans op het ontstaan van onderlinge beschaduwing wat de opbrengst vermindert. De bewerking 'droog' verdient de voorkeur vanwege de hoge efficiency bij stikstofbemesting resulterend in een hoge korrelopbrengst. De bewerking 'nat' wordt alleen uitgevoerd als de weersomstandigheden ongunstig zijn. De bewerking 'onbehandeld' kan tot redelijke opbrengsten leiden, maar de onkruidbestrijding is moeilijk en het aanslaan van het voorgekiemde zaad is onzeker.

References

Abe, K. & N. Yokoi, 1973. Characteristics of heavy paddy soil in Japan. Jap. agric. Res. Q. 7 (2): 81-85.

Abichandani, L.T. & S. Patnaik, 1955. Proper placement of fertilizers. Rice News Teller 3 (1): 12-17.

Ahmad, N., 1963. The effect of evolution of gases and reducing conditions in a submerged soil on its subsequent physical status. Trop. Agric. Trin. 40 (3): 205-209.

Alberda, Th., 1953. Growth and root development of lowland rice and its relation to oxygen supply. Plant Soil 5 (1): 118.

Amson, F.W. van, 1966. Some aspects of clay soils in the Demerara formation of Surinam. Bull. Landb. Proefstn. Suriname 84.

Asami, T., 1971 a. Immobilization and mineralization of nitrogen compounds in puddy soils (part 2). J. Soil Manure Japan 42 (1): 1-44. Engl. Abstr. Soil Sci. Pl. Nutr. 18 (3): 126 (1972).

Asami, T., 1971 b. Immobilization and mineralization of nitrogen compounds in paddy soils (part 3). J. Soil Manure Japan 42 (2): 45-88. Engl. Abstr. in Soil and Pl. Nutr. 18 (5): 200 (1972).

Aspiras, B.B., 1966. Some factors affecting ammonification in flooded soils. M. Sc. thesis, Univ. of the Philippines.

Baars, J.K., 1950. Microbiological processes in rice fields. Landbouw 22: 182-190.

Barber, L.A., M. Ebert & A.T.S. Evans, 1962. Movement of 15 O through barley and rice plants. J. exp. Bot. 13 (39): 397-403.

Basak, M.N. & R. Bhattacharya, 1962. Phosphate transformations in rice soil. Soil Sci. 94: 258-262.

Boer, P.G. de, Mechanization of crop treatment during growth. 1971 F.A.O. Meet. Exp. Mech. Rice Prod. and Proc., Paramaribo. In press.

Bouldin, D.R., 1966. Speculations on the oxidation reduction status of the rhizosphere of rice roots in submerged soils. In: Joint FAO/IAEA Division of Atomic Energy in Agriculture.

Bouma, J., 1969. Microstructure and stability of two sandy loam soils with different soil management. Agric. Res. Rep. (Versl. landbouwk. Onderz.) 724.

Bradley, D.B. & D.H. Sieling, 1953. Effect of inorganic anions and sugars in phosphate precipitation by iron and aluminium as influenced by pH. Soil Sci. 76 (3): 175-178.

Breazeale, J.F. & W.T. McGeorge, 1939. Studies on soil structure: some nitrogen transformations in puddled soils. Tech. Bull. Ariz. agr. Exp. Stn. 69: 225-252.

Brewer, R., 1964. Fabric and mineral analysis of soils. John Wiley, London/ New York/Sydney.

Brinkman, R. & L.J. Pons, 1968. A pedogeomorphological map of the sediments of the coastal plain in the three Guianas. Soil Survey paper 4. Inst. Soil Survey, Wageningen.

Briones, A.M., 1966. Nitrogen availability in five soils under different management systems and its effects on growth and yield of rice. M. Sc. thesis Univ. of the Philippines, 36.

Briones, A.A. & M.E. Raymundo, 1969. The influence of varying depths of mud on the yield of lowland rice. Philipp. Agric. 45 (10): 567-572.
Burgess, P.S., 1921. The soil solution, extracted by Lipmann's direct pressure method, compared with 1:5 water extracts. Soil Sci. 14 (3): 191-216.
Coombs, A.V., 1964. The role of copper sulphate in rice growing. Wld. Crops 16 (2): 83-84.
Chang, S.C., 1964. Phosphorus and potassium tests of rice soil. In: The mineral nutrition of the rice plant. p. 373-381. John Hopkins Baltimore.
Chang, S.C., 1968. Application of phosphorus fractionations to the study of the chemistry of available soil phosphorus. Soils Fert. Taiwan 1-15.
Chayes, F., 1965. Reliability of point counting results. Am. J. Sci. 163: 719.
Chin, W.F. & W. Kroontje, 1963. Urea hydrolysis and subsequent loss of ammonia. Proc. Soil Sci. Soc. 27: 316-318.
Choi, H.D. & D.S. Kim, 1964. Studies on the tolerance of rice plants to salinity. Res. Rep. Office Rural Developm. Office Kereo, Japan 4 (1): 131-138.
Davis, L.L., 1964. Rice production in California. Wld. Fmg. 6 (3): 4-6.
Dei, Y. & K. Maeda, 1973. On soil structure of plowed layer of puddy field. Jap. agric. Res. Q. 7 (2): 86-92.
Dijk, A.D. van, Tillage practices and tillage equipment as used for rice production on large estates in Surinam. 1971 FAO. Meet. Exp. on Mech. of Rice Prod. and Proc. Surinam. In press.
Dirven, J.G.P. & V.K. R. Ehrencroon, 1964. Sporenelementen in weidegronden. Surinaamse Landb. 13: 11-21.
Dumas, R.E., Peasant rice farming in Surinam. 1971 FAO Meet. Exp. on Mech. of Rice Prod. and Proc. Surinam. In press.
Eaton, F.M., R.B. Harding & T.J. Ganje, 1960. Soil solution extractions at tenth-bar moisture percentage. Soil Sci. 90: 253-258.
Ehrencroon, V.K.R., 1963. Salt tolerance of rice. Proc. Congr. Agric. Res. in the Guianas, Paramaribo. Bull. Landb. Proefstn., Surinam, 82.
Eyk, J.J. van der & H.A.J. Hendriks, 1953. Soil and land classification in the old coastal plain of Surinam. Neth. J. agr. Sci. 1 (4): 278-289.
Elias, R.S., 1969. Rice production and minimum tillage. Outl. Agric. 6 (2): 67-71.
Evatt, N.S., 1964. The timing of nitrogenous applications in rice. In: The mineral nutrition of the rice plant. Proc. Symp. Int. Rice Res. Inst. 243-254. John Hopkins Baltimore.
Farr, E., L.V. Vaidyanathan & P.K. Nye, 1969. Measurements of ionic concentration gradients in soil near roots. Soil Sci. 107 (5): 385-391.
Ferrari, Th. J. & J.L. Cuperus, 1973. Dynamic simulation of vertical non-adsorbed anion transport. Plant Soil 38 (2): 425-438.
Fokkens, B. & J. Weyenberg, 1968. Measureing the hydraulic potential of groundwater with the hydraulic potential probe. J. Hydrol. 6 (3): 306-313.
Gardner, W., 1960. Dynamic aspects of water availability to plants. Soil Sci. 89 (2): 63-73.
Garrand, A.M., 1967. Paddy Rice Production. Rome FAO IRC Congress.
Gasser, J.K.R., 1961. Investigations on rice-growing in British-Guiana. I. Characteristics of some rice soils of the coastland. J. Soil Sci. 12: 234-241.
Gasser, J.K.R., 1962. Investigations on rice growing in British Guiana. II. Field experiments to best effects of fertilizers, lime, and cultivations on yield, composition, and nutrient uptake. J. Soil Sci. 13: 321-332.
Goto, J. & K. Lai, 1957. On the differences of oxidizing power of paddy rice seedling roots among some varieties. Soil Plant Food 2: 198-200.
Green, V.E., 1953. Rice-soil conserving or soil depleting. Proc. Soil Sci. Soc. 17 (3): 283-284.

Hall, V.L., L.J. Sims & T.M. Johnston, 1968. Timing of nitrogen fertilization of rice. II. Culm elongation as a guide to optimum timing of applications near mid season. Agr. J. 60: 750-753.
Harada, T. & R. Hayashi, 1968. Studies on the organic nitrogen becoming decomposable through the effect of drying a soil. Soil Sci. Pl. Nutr. 14 (1): 13-19.
Hasselbach, O.E. & F.W. van Amson, 1965. A study of preseasonal cultivation methods in rice. Bull. Landb. Proefstn. Surinam, 65.
Hasselbach O.E. & E. Ubels, 1966. Fosfaatbemesting en droge grondbewerking bij rijst in Suriname. Med. Land. Proefstn. Suriname, 38.
Have, H. ten, 1967. Research and breeding for mechanical culture of rice in Surinam. Thesis Wageningen, Agric. Univ.
International Atomic Energy Agency, Vienna, 1970. Rice fertilization. Techn. Rep. 108.
International Research Institue, Philippines. Annual Reports. 1964, 1966, 1967, 1969, 1972.
Jaw, C.J. & P.K. Lu, 1964. Mechanical properties of paddy soils in relation to their moisture content. Acta pedol. sinica 12: 132-142.
Jayaraman, M., K. Swaminathan & A. Mariakulundai, 1969. Time of application of nitrogen to paddy in the old Cauvery Delta. Mudras agric. J. 55: 243-247.
Jong, G.J. de, 1968. Effect of date and method of application of nitrogen fertilizer on yield and some yield components of cereals. Stikstof 12: 152-156
Jongerius, A., 1957. Morphologische onderzoekingen over de bodemstructuren. Thesis, Wageningen, Agric. Univ.
Jongerius, A. & G. Heintzberger, 1963. The preparation of mammouth-sized thin section. Soil Survey Papers, no. 1, Soil Survey Institute, Wageningen.
Kaddah, M.T., 1963. Salinity effects on growth of rice at the seedling and inflorescence stages of development. Soil Sci. 96 (2): 105-111.
Kamerlingh, G.E., 1974. Thesis Agric. Univ. Wageningen (in press).
Khan, A.U., Present and future development of the mechanisation of rice production. 1971. FAO Meet. Exp. in Mech. of Rice Prod. and Prod. Surinam. In press.
Koenigs, F.F.R., 1963. The puddling of clay soils. Neth. J. agric. Sci. 11 (2): 145-156.
Koyama, T., 1971. Soil-plant nutrition studies on tropical rice. III. The effect of soil fertility status of nitrogen and its liberation upon the nitrogen utilisation by the rice plants in Bangkhen paddy soil. Soil Sci. Pl. Nutr. 17 (6): 210-220.
Koyama, T., C. Chammen & N. Niamsrichand, 1972 a. Soil-Plant nutrition studies on tropical rice. IV. The effect of double cropping in a rainy season upon the plant growth and soil fertility status of nitrogen in the Bangkhen paddy soil. Soil Sci. Pl. Nutr. 18 (1): 23-29.
Koyama, T., C. Chammen & N. Niamsrichand, 1972 b. Soil-Plant nutrition studies on tropical rice. V. Yield components as affected by timing of topdressing of nitrogen in the Bangkhen paddy field. Soil Sci. Pl. Nutr. 18 (6): 233-245.
Kuipers, H., 1957. A reliefmeter for soil cultivation studies. Neth. J. agric. Sci. 5: 255-262.
Kuipers, H., 1963. The objectives of soil tillage. Neth. J. agr. Sci. 11 (2): 91-96.
Len, S.C., 1969. Mechanical land cultivation in padi production. Malay. agric. J. 47 (1).
Madramootoo, H., Tillage practices and tillage equipment for rice production on small family farms. 1971. FAO Meet. Exp. on Mech. of rice Prod. and Proc. Surinam. In press.
Murayama, N., 1967. Nitrogen nutrition of rice plant. Jap. Agric. Res. Q. 2 (2): 1-5.

Matsubayashi, M., T. Nomoto, R. Iro, T. Takase, N. Yamada, 1967. Theory and practice of growing rice. Fuji Publ. Co., Tokyo.
Matsushima, S., 1962. Some experiments on soil-water-plant relationship in the cultivation of rice. Proc. Crop Sci. Soc. Japan 31: 115-121.
Matsubayashi, M., T. Nomoto, R. Iro, T. Takase, & N. Yamada, 1962. Some experiments on soil-water-plant relationship in the cultivation of rice. Proc. Crop Sci. Soc. Japan 31: 115-121.
Matsushima, S., 1969. A method for maximizing rice yield on the basis of V-shaped rice cultivation theory, I, II. Jap. agric. Res. Q. 4 (1), 1-6, (2) 1-5.
Matsushima, S., 1970. Crop science in rice. Theory of yield determination and its application. Fuji Publ. Co. Tokyo.
Meteorologische Dienst Suriname, 1964. Klimatologische tabellen. Diverse elementen. Nieuw Nickerie (1931-1960). maandgemiddelden (Eng. explanation). Rep. serie 3, no. 3.
Miyasaka, A., 1964. Effect of drainage on CO_2 exchange and some characters related to grain yield of rice plant. Proc. Crop Sci. Soc. Jap. 33 (1): 90-93.
Mittra, M.K. & J.W.L. Pieris, 1968. Paraquat as an aid to paddy cultivation. Proc. 9th. Br. Weed Control Conf. 1: 668-674.
Moomaw, J.C. & H.P. Curfs, Some general aspects of rice soil tillage. 1971. FAO Meet. Exp. Mech. Rice Prod. and Proc. Paramaribo. In press.
Okuda, A., J. Takahasji & M. Yoshida, 1960. On the volatilization of the ammonia transformed from urea applied under upland and waterlogges conditions. J. Soil Manure, Japan 31 (6): 273-278. Translated by M. Yoshida.
Olsen, S.R., C.V. Cole, F.S. Watanabe & L.A. Dean 1954. Estimation of available phosphorus in soils by extraction with $NaHCO_3$. Circ. Dic. Soils U.S. Dept. Agric., 939.
Ota, Y., 1970. Diagnostic methods for the measurement of root activity in rice plant. Jap. agric. Res. Q. 5 (3): 1-6.
Overwater, C., 1960. Tien jaren Prins Bernard polder. De Surin. Landb. 8 (5): 161-218.
Overwater, C., Factors to be considered for efficient mechanisation of rice production on large estates. 1971. FAO Meet. Exp. on Rice Prod. and Proc. Surinam. In press.
Pan, C.L., 1964. The effect of salt concentrations of irrigation water on the growth of rice and other related problems. Int. Rice Commn. Newl. 13 (2): 4-13.
Patnaik, S. & F.R. Broudbent, 1967. Utilisation of tracer nitrogen on rice in relation to time of application. Agr. J. 59 (3): 287-288.
Patrick, W.H. & R. Wyatt, 1964. Soil nitrogen loss as a result of alternative submergence and drying. Proc. Soil Sci. Soc. 28: 647-653.
Patrick, W.H.jr. & F.J. Peterson, 1967. Placement of nitrogen fertilizer. Bull. Louis. agric. Exp. Stn. 49.
Patrick jr., W.H.M. & I. C. Mahapatra, 1967. Nitrogen and phosphorus in waterlogged soils. Adv. Agron. 20.
Patrick jr. W.H.M.., F.J. Peterson & F.T. Turner, 1968. Nitrification inhibitros for lowland rice. Soil Sci. 105 (2): 103-105.
Pearson, G.A. & L. Bernstein, 1959. Salinity effects at several growth stages of rice. Agr. J. 51: 654-657.
Pearson, G.A., 1961. The salt tolerance of rice. Int. Rice Commn. Newsl. 10 (1): 1-4.
Pearson, G.A., A.D. Ayers & D.L. Eberhard, 1966. Relative salt tolerance of rice during germination and early seedling development. Soil Sci. 102 (3): 151-156.
Peterson, F.J., M.B. Sturgis & R.J. Miears, 1963. Louisiana Agric. Expt. Sta. Bull. 569.

Plas, L. van der & A.C. Tobi, 1965. A chart for judging the reliability of point counting results. Am. J. Sci. 263: 87.
Ponnamperuma, F.N., 1964. Dynamic aspects of flooded soils. In: The mineral nutrition of the rice plant. 285-327. John Hopkins Baltimore.
Raalte,M.H. van, 1941. On the oxygen supply of rice roots. Ann. Gdn. Buitenz. 51: 43-57.
Racho, V.V. & S.K. De Datta, 1968. Nitrogen economy of cropped and uncropped flooded rice soils under field conditions. Soil. Sci. 105 (6): 419-427.
Reed, F.J., 1939. Chemical characteristics of the soils of the rice area of Louisiana. La. agric. Exp. Sta. Bull. 307.
Reyne, A., 1961. On the contribution of the Amazone river to accretion of the coast of the Guianas. Geologie Mijnb. 40: 219-226.
Rodrigo, D.M., 1961. The relationship between chemical and physico-chemical characteristics of paddy soils in the dry state and continual submergence. Trop. Agr. Ceylon 117: 245-272.
Rodrigo, D.M., 1966. 10th Meeting working part rice soils, water and fertilisation practices. Intern. Rice Comm. FAO-Un. Lake Charles, Louisiana, U.S.A.
Sahu, J., 1968. Minimum tillage using grammoxone for rice production. Indian. J. agric. Sci. 30 (6): 473-481.
Saito, M. & K. Kawaguchi, 1971. Flocculating tendency of paddy soils (part 4). Soil structure of paddy plow-layers. J. of Sci. of Soil and Manure Japan. 42, no. 3: 89-132. Engl. abstr. Soil Sci. Pl. Nutr. 18 (5): 202.
Sanchez, P., 1968. Rice performance under puddled and granulated soil cropping systems in south east asia. Cornell Univ. ph.d. thesis microfilm. 69-5032.
Seko, H., 1966. Lowland rice and upland farming in Japan. Ministry of Agriculture and Forestry, Japan.
Seth, A.K., C.H. Khaw, A. Arope & K.K. Awyong, 1969. A new approach to padi cultivation using paraguat aided minimal and zero tillage technique. Crop production seminar FAO, Exp. Stn. Sungei Besi, Selangur.
Shioiri, M., 1954. The chemistry of paddy soils in Japan. Ministry of Agriculture and Forestry, Japan.
Sims, J.L., V.L. Hall & T.H. Johnston, 1967. Timing of N fertilisation of rice. I. effect of applications near midseason on varietal performance. Agr. J. 59: 63-66.
Sims, J.L. & G.A. Place, 1968. Growth and nutrient uptake of rice at different growth stages and nitrogen levels. Agr. J. 60: 692-696.
Simsiman, G.V., S.K. De Datta & J.C. Moomaw, 1967. Sources of nitrogen and methods of application for flooded rice. J. agric. Sci. 69: 189-196.
Singh, J.H. & T. Takahashi, 1962. Effect of varying dates of top-dressing of nitrogen on plant characters leading to tendency to lodging in rice. Soil Sci. Pl. Nutr. 8 (5): 169-176.
Soil Servey Manual, 1962. U.S. Dept. Agric. Handbook 18.
Soil Classification, a comprehensive system, 1967. U.S. Dept. Agric.
Strickland, R.W., 1969. Fluctuations in available mineral nitrogen in a flooded rice soil on the sub-coastal plains of the Adelaide River. A.T. Australia. Aust. J. Expl. Agr. and An. Husb. 9: 532-540.
Tanaka, I., K. Nojima & J. Uemura, 1963. The influence of drainage on the growth of paddy rice. Proc. Crop Sci. Soc. Japan 32 (1) 89-93.
Tanaka, A. & S.A. Navasero, 1964a. Loss of nitrogen from the rice plant through rain or dew. Soil Sci. Pl. Nutr. 10 (1): 36-39.
Tanaka, A., S.A. Navasero & C.V. Garcia, 1964b. Growth habit of the rice plant in the tropics and its effect in nitrogen response. Tech. Bull. Int. Rice Res. Inst. Phillipp. 3.

Tanaka, A., C.V. Garcia & Nguyen-Thi Diem, 1965a. Studies of the relationship between tillering and nitrogen uptake of the rice plant. part 1. Soil Sci. Pl. Nutr. 11 (1): 9-13.

Tanaka, A. & C.V. Garcia, 1965b. Studies of the relationship between tillering and nitrogen uptake of the rice plant. part 2. Soil Sci. Pl. Nutr. 11 (3): 129-135.

Tanaka, A & K. Kawano, 1965c. Leaf characters relating to Nitrogen response in the rice plant. Soil Sci. Pl. Nutr. 11 (6) 251-258.

Ubels, E., 1960. Modernisering van de rijstbouw in Nickerie. Meded. Landb. Proefstn. Suriname 26.

Williams, W.A., D.S. Nikkelsen, R.E. Mueller & J.E. Ruckman, 1968. Nitrogen immobilization by rice straw incorporated in lowland rice production. Plant Soil (1):49-59.

Wit, Th.P.M. de, 1960. The Wageningen rice project in Surinam. thesis, Wageningen University. Meded. L.H.

Wyche, R.H. & R.L. Cheaney, 1940. Effect on rice yields of nitrogenous fertilizers applied as a topdressing to dry, wet and flooded soils. Prog. Rep. Tex. agr. Exp. Sta. 1207.

Yamasaki, S. & A. Kishita, 1972. Studies on soil solution with reference to nutrient availability. I. Effect of various potassium fertiliser on its behavior in the soil solution. Soil Sci. Pl. Nutr. 18 (1): 1-6.

Yoshida, T., 1966. Methods of measuring root activity. J. Soc. Sci. Soil Manure Japan, 37 (1): 63-68.

Use was made of the following reports:

Amson, F.W. van, 1968. Bodemfaktoren en rijstproducties. Verslag van een onderzoek. Rapport Landbouwproefstation, Paramaribo, Suriname.

Bipat, R. & G.E. Kamerling, 1966. Bepaling van de doorlatendheid met behulp van de boorgaten en de piezometer methode. Rep. no. 81. Agr. Hydr. Ondz. Landbouwproefstation, Paramaribo, Suriname.

Blok, F., 1972. Bepaling van de hoeveelheid voor rijstgroei beschikbaar fosfaat vgl. Olsen aan de veldvochtige grond. Ing. scriptie Agric. Univ. Wageningen. Soils and Fertilisers Dept.

Boons, H. & W. Scheltema, 1971. De stabiliteit van de bouwvoor der rijstgronden in Nickerie. Intern. Rep. Bod. Cult. Ond. no. 45 S.M.L. Wageningen, Suriname.

Brinkman, R., 1960. Onderzoek kleimineralen, kustvlakte van Suriname en Venezuela, Delta Amacuro. unpublished report. Dienst Bodemkartering, Paramaribo, Suriname.

Broek, B. van den, 1968. Bodemkundige en mechanisatie aspecten van het Wageningen project gedurende de jaren 1961 t/m 1968. S.M.L. Report Wageningen, Surinam.

Elders, H.A.J. & G.E. Kamerling, 1967. Enige doorlatendheidsmetingen bij kleigronden in de jonge kustvlakte van Suriname. Rep. Agr. Hydr. Onderz. no. 51. Landbouwproefstation, Paramaribo, Suriname.

Fortanier, E.J., 1962. Repport inzake het onderzoek naar de mogelijkheden van verbouw van tweede gewassen en boomcultures voor het Wageningen-project Suriname. Rep. S.M.L. Wageningen, Suriname 187 p.

Kamerling, G.E., 1963. Enige voorschriften van het bodemchemisch laboratorium. Agr. Hydr. Onderz. Intern Rep. no. 4. Landbouwproefstation, Paramaribo, Suriname.

Kamerling, G.E., 1970. Enkele metingen met betrekking to de transpiratie en de evapotranspiratie van bevloeide rijst. Rep. Agr. Hydr. Onderz. no. 273. Landbouwproefstation, Paramaribo, Suriname.
Koninklijk Instituut van de Tropen, 1955. Analyse grondmonsters. S.M.L. typed report. Amsterdam, Holland.
Kras, C.R., 1953. Verhandelingen over het klimaat van S.M.L. Wageningen, Suriname. stenceled report.
Leyser, J., 1970. Effecten van de grondbewerking op de stikstofhuishouding van de Wageningse rijstgronden o.a. emmerproef. Intern Rep. Bod.-Cult. Ond. no. 40. S.M.L. Wageningen, Suriname.
Lienen, B.A.P. & W. Scheltema, 1971. Waterbeweging en temperatuur. IV. piezometrische niveau's, vochtspanning en temperatuur metingen in 1970-H. Intern Rep. Bod. Cult. Ond. no. 30. S.M.L. Wageningen, Suriname.
Magnage, C.P., 1968. Time of nitrogen application for flooded rice. International Rice Research Institute. Saturday Seminar 26-10-68. The Philippines.
Mensvoort, M.E.F., 1972. Micromorfologie van rijstgronden uit de jonge Surinaamse kustvlakte. Master scription Agricultural University, Wageningen. Regional Soil Science Dept.
Poels, R.L.H. & W. Scheltema, 1969. Waterbewging I. Onderzoek naar de waterbeweging in de bodem van natte rijstvelden met behulp van piezometerbuizen. Intern. Rep. Bod. Cult. Ond. no. 9, S.M.L. Wageningen, Suriname.
Rellum, P.D. & W. Scheltema, 1971. Grondbewerking, zaaidichtheid en stikstofbemesting. Intern. Rep. Bod. Cult. Ond. no. 21, S.M.L. Wageningen, Suriname.
Scheltema, W., 1965. De invloed van de magnesium op de structuur van kleigronden. Ing. scriptie. Agric. Univ. Wageningen. Soils and Fertilizers Dept.
Staveren, K. van, 1973. Stikstofonderzoek in rijstpolders in de jonge kustvlakte in het Nickerie district in Suriname. Ing. scriptie Wageningen. Soils and Fertilizers Dept.
Yoshida, T., 1968. Nitrogen fixation in rice fields. Intern. Rice Res. Institute. I. Saturday seminar. May 18. The Philippines.