7.1 Reclamation

J. Wolf

7.1.1 Introduction

The productivity of agricultural land is to a large extent determined by the moisture regime of the soil. Potential production can only be attained if the soil-moisture content during the entire crop growth cycle can be maintained within the optimal range. Reclamation can be considered as the total of operations required to lenghten the period of optimal soil-moisture for crop growth.

Reclamation measures consist mainly of excavation and movement of earth. These activitites require a large amount of labour and/or machinery, but they are needed only once or with long intervals in between. This in contrast with many other operations in agricultural production, which mostly have to be repeated for every planted crop (Section 6.1). In this section only reclamation measures carried out on the farm by the farmer and his family are considered. Macro-structures like canals, dams, dikes, etc., are assumed to be constructed by the government and are not taken into consideration. Also, measures like reclamation of saline or very acid soils are not considered here.

Four schematic levels of reclamation can be distinguished:

Reclamation Level I: natural situation; agricultural use limited to extensive grazing, food gathering and fuelwood collection; moisture regime is fully dictated by the weather conditions; this level will not be treated here.

Reclamation Level II: simple clearance; forest clearing or burning of vegetation, more permanent cultivation with or without fallow periods, field-protecting floodwalls, bunds to permit the cultivation of rainfed rice; moisture regime is fully dictated by the weather conditions; range of soil-moisture contents from very low to very high.

Reclamation Level III: control of excess water; completion of clearance; levelled or terraced land; field-protecting floodwalls, drainage by open ditches; range of soil-moisture contents from very low to optimal.

Reclamation Level IV: complete water control; well levelled or terraced land; infrastructure for complete water control; sufficient water available for irrigation; optimal soil-moisture content throughout.

In the following subsections, first the main effects of reclamation are treated. Then the consequences of improving the water regime are further illustrated by discussing the results of some computer simulations for a loamy fine sand in northern Thailand. Last, the physical inputs that are needed on the farm for the transfer of land from one Reclamation Level to the next are considered.

7.1.2 Effects of reclamation

Reclamation has various positive effects. In the first place, it makes crop growth possible or improves it, so that higher yields may be achieved. Second, the number of crop species that may be grown is increased, as is the freedom of choice with respect to the time of sowing. In addition, it results in a decrease in fertilizer requirements. These positive effects will be considered in more detail in this subsection.

The gross assimilation rate of a crop is reduced when the soil-moisture content is outside its optimal range, as discussed in Section 3.2 and summarized in Table 80.

At Reclamation Level II, the soil-moisture content may range from very low to very high, at Reclamation Level III from very low to optimal and at Reclamation Level IV the soil-moisture content is in the optimal range throughout, barring exceptional weather conditions. The yield level will be reduced proportionally to the period and the degree of sub-optimum soil-moisture conditions, as discussed in Section 3.4 for Production Situation 2.

It has been shown in Section 6.1 that one of the factors, determining the workability of the land is its moisture content. Depending on the cultivating equipment that is used and the type of soil, there is a lower limit of the soil-moisture suction at which the land can be worked without too much damage. Initially, three technology levels are distinguished for the field work, (1) manual labour, (2) use of animal drawn equipment and (3) light or heavy mechanical equipment. The critical limits for the three levels in terms of soil-moisture suction are assumed to be 10, 100 and 500 cm, respectively. The reclamation level also determines the range of soil-moisture suction in the soil. At

Table 80. The influence of the moisture content of the soil on gross assimilation rate.

Moisture content (SM)*						Reduction factor for gross assimilation rate
very low	SM	$<$	SM_w			0
low	SM_w	$\leq$	SM	$<$	SM_{cr}	$(SM-SM_w)/(SM_{cr}-SM_w)$
optimal	SM_{cr}	$\leq$	SM	$<$	SM_{100}	1
high	SM_{100}	$\leq$	SM	$\leq$	$(SM_0 - 0.05)$	$((SM_0 - 0.05) - SM) / ((SM_0 - 0.05) - SM_{100})$**
very high	SM	$>$	$(SM_0 - 0.05)$			0**

* SM_w, SM_{cr}, SM_{100} and $SM_0 - 0.05$ are the soil-moisture contents at wilting point, at the critical value for optimal growth, at a soil suction of 100 cm and at a soil air content of 0.05 $cm^3\ cm^{-3}$, respectively.
These moisture contents are different for different soils.

** For rice, reduction factor is equal to 1.

Levels III and IV, it is in general not lower than 100 cm, so operations at Technology Levels 1 and 2 are always possible. At Reclamation Level II under natural drainage, the soil-moisture suction may be so low that it is impossible to work the land, even manually, except of course for the cultivation of bunded rice.

At the onset of crop growth, the soil should be sufficiently moist to enable germination and, in the case of a clay soil, to allow the necessary tillage operations. It is assumed that the risk of early crop failure due to lack of water is sufficiently small if sowing is postponed till the moment that the soil-moisture suction is less than 300 cm, or cumulative rainfall over the last 20 days exceeds 7.5 cm. In this way, the beginning of the growing season on soils at Reclamation Levels II and III is fully determined by the rainfall pattern. As a consequence, the season may become too short to grow certain crops that would otherwise be preferred. The possibility of irrigation at Reclamation Level IV makes the farmer, in this respect, independent of rainfall.

At Reclamation Level II shallow groundwater tables may occur. A groundwater table within 10 cm of the rooting depth will result in reduced root activity and eventually lasting damage to the root system due to lack of oxygen in the root zone. The minimum groundwater depth that may occur limits, therefore, the number of crop species that can be grown, because crops differ distinctly in their depth of rooting, as shown in Table 81.

In climates with erratic rainfall on land at Reclamation Levels II and III, deep-rooted crops with a low critical moisture content (Section 3.2, Table 20) must be selected, because these will be less adversely affected by dry periods.

Exercise 91

Which crops are not affected by an average groundwater depth of 1 m below the surface?

Which crops are best adapted to climates with irregular rainfall (in the absence of irrigation)?

The effect of reclamation on the availability of plant nutrients is treated as in Section 4.1. The relation between fertilizer application and yield is laid out in two relations: one between uptake and yield and one between the amount of fertilizer applied and uptake. Both relations are affected by reclamation, as illustrated in Figure 71.

The uptake-yield curve for a particular element is characterized by its initial slope and the maximum yield that may be achieved at an optimal supply of the nutrient. The initial slope is mainly a crop characteristic and is affected only indirectly by environmental conditions, for instance if at Reclamation Levels II or III a sub-optimal water supply during seed filling reduces the seed/straw ratio.

Table 81. Indicative rooting depth of major crops.

crop species	rooting depth (cm)
sugar-cane	160
sorghum	150
cotton	135
maize	135
barley	125
black mustard	125
jute	125
lentil	125
rape seed	125
sesame	125
wheat	125
sweet potato	120
cassava	100
cowpea	95
gram	95
kheshari	95
chilli	90
rice	80
groundnut	75
kenaf	75
mung bean	75
tobacco	75
potato	50
onion	40

Exercise 92

Do you expect an increase or a decrease of the ratio of yield to uptake as a result of a reduced seed/straw ratio. Explain your answer. Draw an uptake-yield curve in Figure 71 that could be the result of the reduced seed/straw ratio.

If the average sub-optimal soil-moisture content during seed filling is known, is it possible to estimate the maximum yield and the ratio between yield and uptake compared to that at optimal water supply during seed filling. How would you do that? Explain your answer.

One of the main purposes of reclamation is to improve crop water supply, which is reflected directly in an increase in the maximum yield that can be

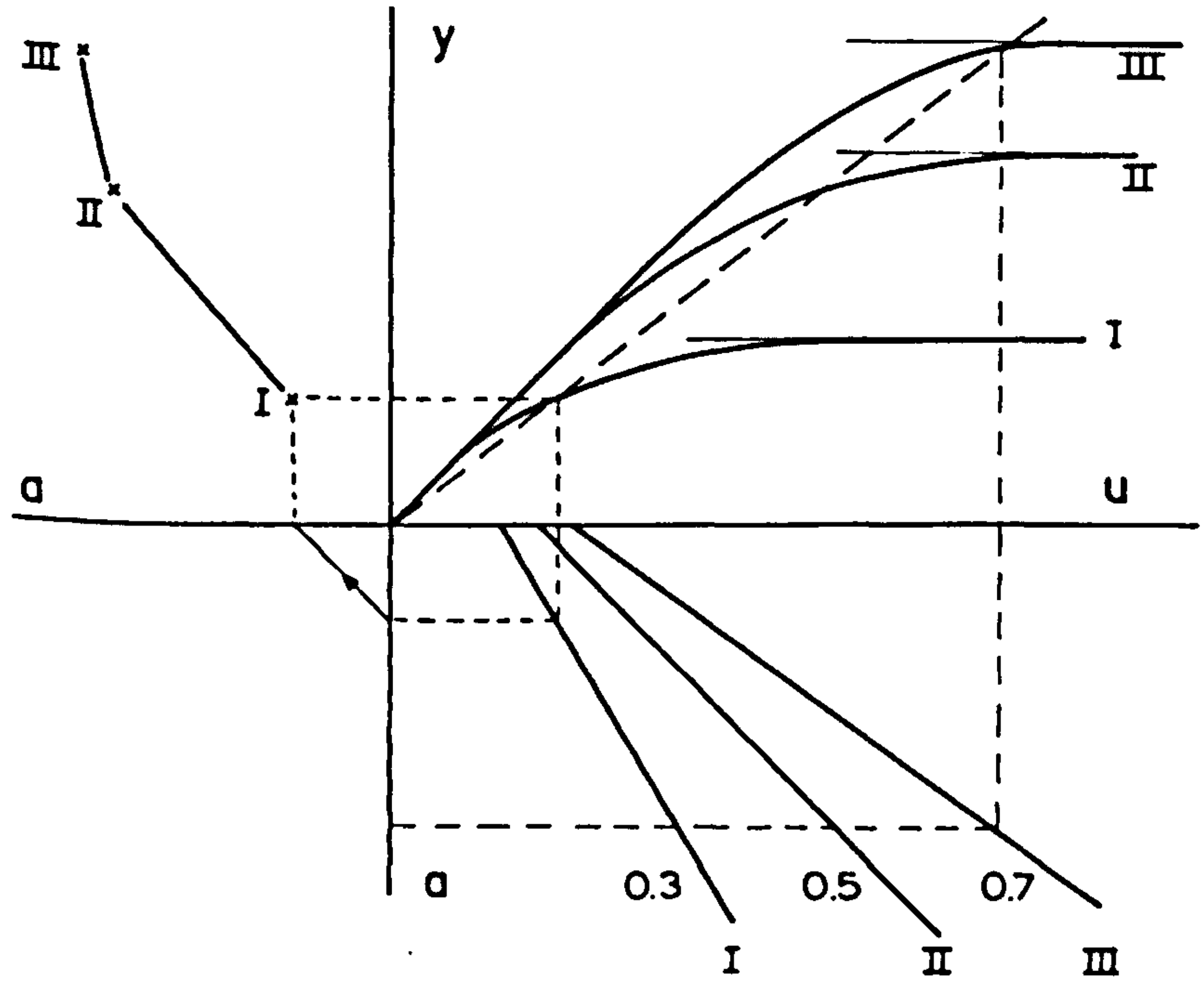

Figure 71. The effect of various reclamation levels (I, II, III) on the relation between fertilizer uptake (u) and yield (y), on the relation between fertilizer application rate (a) and uptake, and on the relation between fertilizer application and yield.

achieved. The nutrient requirement increases linearly with that yield. The amount of fertilizer needed to meet that requirement, depends on the recovery of the fertilizer and the amount of nutrients taken up from unfertilized soil. In general, both are favourably affected by reclamation because better water control stimulates the activity of the root system, contributes to an increased mineralization of the soil organic matter, decreases losses by leaching and leads to lower losses by denitrification because of reduced waterlogging. Although generalizations in quantitative terms cannot be made, it may be concluded that the fertilizer requirement increases less than proportionally with the yield increase due to reclamation. Examples are found in Section 4.1.

The effects of reclamation measures are treated in this section by comparing crop growth at Reclamation Level II with that at higher reclamation levels. Of course these effects are mainly positive, because otherwise the large amount of physical inputs would not be worthwhile. However, when considering clearing of the original vegetation (Reclamation Level I) to allow cultivation of the land, attention should be paid to possible adverse effects.

On slopes of more than 8 to 15% (depending on soil erodibility, slope length, rainfall intensity, etc.) a permanent cover should be maintained by a perennial crop, such as a tree crop, pasture or forest, as indicated for recommended land use in Table 85. Otherwise, soil erosion may result in rapid loss of topsoil, causing a decline in soil fertility and soil structure. Moreover, gullies may be formed accelerating erosion even more. Adverse effects may also appear in coastal areas after reclamation of alluvial soils, deposited in brackish water. Such soils often become very acid after drying and aeration.

Only when the groundwater table can be maintained at a shallow depth (Reclamation Level IV), may cultivation – mainly of rice – be possible on these soils.

Tropical rain forests grow partially on very poor soils. After clearing the original vegetation, the soil organic matter decomposes at a very high rate under the hot, wet tropical climate. This results in a rapid loss of soil fertility built up in the course of time (Section 6.2) and a substantial decrease in the moisture- and nutrient-holding capacity of the soil. Within a short time after clearing the land the production capacity may have declined to such a level that crop production is no longer worthwhile. In addition, fertilizer application is not very effective on these degraded soils because of the low moisture- and nutrient-holding capacity, which results in rapid leaching of nutrients under the high intensity of the tropical rainfall regime. A long bush-fallow period of 10 to 50 years is the best way to restore soil fertility and soil structure. Permanent cultivation on these poor tropical soils appears to be almost impossible.

7.1.3 A simulated example

In this subsection important differences between the Reclamation Levels II, III and IV are illustrated by means of results obtained using a simulation model that calculates the yield levels for Production Situations 1 and 2 (chapter 9). They refer to a slightly undulating, elevated lowland area with a soil of loamy fine sand texture in northern Thailand. The physical characteristics of the soil are given in Table 82.

The climate in the region is of a rather pronounced monsoon type, with the wet season starting in the beginning of April and ending in November. The simulations are for the year 1974, which had a rainfall of 1440 mm and a potential evapotranspiration of 950 mm from April to November. In the calculations, groundnuts are grown both as an early- and as a late-season crop.

The onset of the rains is so distinct that emergence of the early-season crop

Table 82. Physical characteristics of the loamy fine sand, used for the simulation exercise.

Physical characteristic	Value for exercise
Saturated hydraulic conductivity (k_0)	26.5 cm d^{-1}
Total pore space fraction (SM_0)	0.439 cm^3 cm^{-3}
Texture specific geometry factor (γ)	0.0312 cm^{-2}
Field capacity (suction)	ψ = 200 cm (pF = 2.3)
Field capacity (moisture content)	SM = 0.183 cm^3 cm^{-3}

for all three levels of reclamation was during the 14th ten-day period of the year. Under irrigation, emergence could have been shifted to an earlier moment, but this was not done to facilitate comparison. Emergence of the late-season crop was set at the 31st ten-day period of the year, in November. The variety chosen has a growth period of 100 days, so the growth of the late-season crop extends until the beginning of February, well into the dry season. The early-season crop has to be harvested in the middle of the wet season.

It is assumed that during the dry season preceding the early-season crop the land was fallowed and kept free of weeds. Thus after the topsoil has dried out totally by evaporation, no water loss from the profile by evapotranspiration or drainage will take place. This results in a soil at about field capacity with a mulch layer on top at the start of the wet season.

Crop failure will occur when the air content in the root zone is lower than 0.05 $cm^3\ cm^{-3}$ for more than 20 consecutive days. At Reclamation Level II, with no control of excess water, this occurs directly after emergence for both the early- and late-season crop. For the late-season crop this can be avoided by sowing later, but then germination problems may occur because of drying out of the topsoil. In addition, too much water may be lost by direct evaporation from the soil surface. To conclude, the conditions at this low level of reclamation are not suitable for groundnut cultivation. The land should be used for crops that prefer or can stand waterlogged soils, such as bunded rice.

For both the early- and late-season crop of groundnuts grown at Reclamation Level III, the values of the various terms of the water balance, the soil-moisture content and some growth characteristics are given by ten-day period in Table 83, together with the technology level, the rainfall and the potential evaporation. The cumulative values of the terms of the water balance for the whole season and the yield of pods for Reclamation Levels III and IV are summarized in Table 84.

Because of the drainage at Reclamation Level III, the soil-moisture content during growth of the early-season crop is maintained at field capacity, i.e. 0.183 $cm^3\ cm^{-3}$, except between the 18th and 20th ten-day periods, a time of relatively little rain. At Reclamation Level IV, 90 mm of water is given during this period. This results in a slight increase in actual evapotranspiration, but hardly affects yield. As the groundnut crop is supposed to be growing under optimal nutrient supply, the simulated yields at both reclamation levels are those of Production Situation 1.

At the end of the wet season there is considerable drainage during the 30th and 31st ten-day periods, so that at Reclamation Level III the crop does not fail because of waterlogging. The rain stops rather abruptly, so that water stress starts to develop already in the third ten-day period of growth. At maturity, soil-moisture is practically exhausted and due to water stress during the major part of the growing period, the simulated yield is only 1100 kg pods ha^{-1}. At Reclamation Level IV, irrigation starts in the 33rd ten-day period and is continued into the second ten-day period of the following year. A total

Table 83a. The simulated terms of the water balance and some simulated growth charac
an early planted crop of groundnut. Emergence at 14th 10 day period of the year.

10 day period	10	11	12	13	14
rain (mm per 10 day period)	0	0	20	160	48
mulch[a]	m	m	m		
potential evaporation (open water), (mm per 10 day period)	60	62	60	56	54
actual evapotranspiration, (mm per 10 day period)	0	0	22	22	20
drainage (mm per 10 day period)	0	0	0	120	30
pF	2.3	2.3	2.3	2.3	2.3
soil moisture content ($cm^3 cm^{-3}$)	0.183	0.183	0.183	0.183	0.183
leaves, live weight ($kg ha^{-1}$)					⩽100
weight pods ($kg ha^{-1}$)					
technology level	3	3	3	2	2

[a]m means present.

Table 83b. The simulated terms of the water balance and some simulated growth characte
late planted crop of groundnut. Emergence at 31st 10 day period of the year.

10 day period	27	28	29	30	31
rain (mm per 10 day period)	66	30	8	50	116
mulch					
potential evaporation (open water), (mm per 10 day period)	42	40	40	42	36
actual evapotranspiration, (mm per 10 day period)	16	16	16	16	14
drainage (mm per 10 day period)	50	10	0	30	100
pF	2.3	2.3	2.3	2.3	2.3
soil moisture content ($cm^3 cm^{-3}$)	0.183	0.183	0.183	0.183	0.183
leaves, live weight ($kg ha^{-1}$)					⩽100
weight pods ($kg ha^{-1}$)					
technology level	2	2	2	2	2

of 100 mm of water was given, which more than doubled the yield. Not surprisingly, the growth of such a late-season crop is considerably improved by irrigation.

Only during seedbed preparation and sowing of the early crop, and during harvest of the late crop, is the soil dry enough to permit use of the heavy equipment associated with Technology Level 3. Harvesting of the early crop and seedbed preparation for and sowing of the late crop is carried out well within the wet season, but then only the light equipment of Technology Level

16	17	18	19	20	21	22	23
54	66	12	6	14	136	72	38
50	48	48	48	48	50	46	44
36	40	40	40	40	42	30	22
20	30	0	0	10	40	120	0
2.3	2.3	2.5	3.0	3.4	2.3	2.3	2.3
0.183	0.183	0.156	0.099	0.065	0.183	0.183	0.183
1300	2000	2500	2700	1600	700	200	⩽100
		200	500	1000	1600	2100	2300
2	2	2	3	3	2	2	2

33	34	35	36	1	2	3	4
0	0	16	0	0	0	0	0
32	30	28	32	30	32	38	38
16	22	22	26	22	12	4	4
0	0	0	0	0	0	0	0
2.4	2.7	2.8	3.1	3.5	3.8	3.9	3.9
0.169	0.131	0.120	0.090	0.058	0.040	0.035	0.035
800	1400	1900	2200	1500	600	⩽100	⩽100
		200	500	900	1100	1100	1100
2	3	3	3	3	3	3	3

2 can be used. Fully mechanized agriculture is therefore not possible on this soil in this region.

Exercise 93

Yield of the late-season crop of groundnut at Reclamation Level III is seriously reduced compared to the yield of irrigated groundnut (Table 84). Calculate the critical soil-moisture content at a maximum transpiration rate of 2.5 mm

Table 84. Summarized data for the whole growth period

	Reclamation level III		Reclamation level IV	
	early crop	late crop	early crop	late crop
Rain (mm)	838	304	838	304
Irrigation (mm)	—	—	130	100
Actual evapotranspiration (mm)	378	220	404	252
Drainage (mm)	460	190	560	190
Soil moisture increase (mm)	0	-106	+4	-38
Yield of pods (kg ha $^{-1}$)	2300	1100	2300	2400

d^{-1} on loamy fine sand (SM_0 = 0.439 cm^3 cm^{-3}, γ = 0.0312). Use Table 20 and Equation 53.
Estimate the number of days of unrestricted assimilation starting from the 35th ten-day period (end of rainfall), using a rooting depth of 75 cm and a maximum transpiration rate of 2.5 mm d^{-1}.

Exercise 94
Calculate the reduction in gross assimilation rate (see Table 80) at Reclamation Level III in ten-day periods 36, 2 and 4, compared to the assimilation rate of irrigated groundnuts.

Exercise 95
Repeat the calculations of Exercise 94 for sorghum, wheat and onion using the same data, except for the soil-water depletion factor p and the rooting depth. Which crop will perform best in this period?

7.1.4 Physical inputs for reclamation

Physiography, slope and soil type are the main determinants of the type and amount of physical inputs needed for reclamation. For example, erosion control is hardly needed on level lowland, flood control is superfluous in the uplands, the steepness of the slope determines the amount of earth movement for ridging and terracing, and it is more difficult to move clay than sand. In a-

Table 85. Geographical classification of Thailand.

Land unit	Characteristics	N_r	h_r, h_b	N_t	Slope (%)	Naturel drainage	Recommended landuse
U1	lowland, level	0	0.5	3	0-3	moderate	bunded rice
U2	elevated lowland, level to undulating	3	0.5	4	0-8	moderate	bunded rice, field crops
U3	upland, level to undulating	3	0.5	4	0-8	well	upland rice, field crops, tree crops
U4	upland, undulating to rolling	6	0.8	7	8-15	well	field crops, tree crops, grazing
U5	upland, rolling to steep	9	1.0	10	15-30	well to excessive	tree crops, grazing, forest
U6	lowland, flooded	3	0.5	4	0-8	various	floating rice, swamp, wet forest
U7	upland, steep	9	1.0	10	>30	excessive	forest, waste land

N_r is number of ridges required for erosion control for a plot of 100 × 100 m.
h_r is height of ridges for erosion control (m).
N_t is number of required terraces for a plot of 100 × 100 m.
h_b is height of bunds, equal to height of ridges (m).

schematized setup, seven land units have been distinguished in Thailand, ranging from level lowland to steep upland. These land units are characterized in Table 85 in terms of slope, the degree of natural drainage and recommended land use. The example of the previous subsection referred to Land Unit U2, level to undulating elevated lowland with a slope between 0 and 8 percent and moderate natural drainage. The soil is a loamy fine sand.

For a proper assessment of reclamation possibilities, reasonable estimates of labour requirements for upgrading land from one reclamation level to the next are necessary, because the labour requirements for reclamation are high if carried out in hand labour. Because most soils can only be worked in the growing season, when labour requirements for other activities are also high, labour is often the limiting resource. That is the reason why in most instances heavy earth-moving equipment is used.

To upgrade an hectare of Land Unit U2 from its more or less natural situation of Reclamation Level I to Reclamation Level II, the vegetation has to be destroyed by slashing and burning. In this activity heavy trees, tree stumps and termite hills are not removed. Manually this would take about 300 man-hours per hectare, but if heavy equipment were to be used the labour requirement is reduced to about 7 man-hours per hectare. This machinery can also be used to build flood walls, needed to protect against high water levels. Manually this would take 100 man-hours per hectare, but with heavy equipment it is reduced to about 8 man-hours. Because the land is undulating, some erosion control by contour ridging is necessary. On this land unit, 3 ridges per 100 metre of field length will on the average suffice. Assuming ridges with a width and height of 0.5 metre and a length of 300 m ha^{-1}, the necessary earth movement amounts to 37.5 m^3 ha^{-1}. If done by hand, that will take for a loamy fine sand about 20 man-hours per hectare.

The calculations presented in the previous subsection show that the chances of crop failure due to waterlogging are high, so that the farmer will probably choose for bunded rice. In that case bunds must be constructed that have the same dimensions as the ridges. To increase the surface storage capacity, the number of bunds has to be higher than needed for erosion control. The bunds are placed at an average distance of about 6 m, so about 1600 m of bund is needed per hectare. The labour requirement for their construction is about 100 man-hours per hectare.

Assuming that a main road system is provided, the land has to be opened up by simple dirt paths. At this reclamation level, 50 m of path, one m wide, per hectare will suffice. This requires an earth movement of 10 m^3 ha^{-1} or 5 man-hours of manual work. The total labour requirement for construction of roads and bunds is about 100 man-hours per hectare. This is still very small compared with the 1000 man-hours of work needed for the cultivation of 1 hectare of bunded rice. It is therefore likely that the time for this work can be found, provided the land is cleared and protected against floods.

To upgrade land from Reclamation Level II to Level III, the land has to be

Table 86. Productivity for excavation and movement of earth.

		Moving distance (m)									units
		0	10	20	30	40	50	60	70	100	
bulldozer	clay	100	85	71	55	46	40	34	31	23	m^3h^{-1}
bulldozer	sandy soil	140	120	100	78	65	56	48	43	32	m^3h^{-1}
manual, digging + loading	clay	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	m^3h^{-1}
manual, digging + loading	sandy soil	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	m^3h^{-1}
manual, wheel barrow transport	clay	4	4	2.8	2.1	1.8	1.5	1.4	1.3		m^3h^{-1}
manual, wheel barrow transport	sandy soil	4	4	2.8	2.1	1.8	1.5	1.4	1.3		m^3h^{-1}
manual total[a]	clay	1.08	1.08	1.19	1.31	1.39	1.50	1.54	1.60		hm^{-3}
manual total[a]	sandy soil	0.68	0.68	0.79	0.91	0.99	1.10	1.14	1.20		hm^{-3}
manual total[a]	clay	0.93	0.93	0.84	0.76	0.72	0.67	0.65	0.63		m^3h^{-1}
manual total[a]	sandy soil	1.47	1.47	1.27	1.10	1.01	0.91	0.88	0.83		m^3h^{-1}

[a] Calculation procedure, for example manual, clay, moving distance 30 m:

$\frac{1}{1.2} + \frac{1}{2.1} = 1.31\ h\ m^{-3}$. So the average productivity for digging and transport is $1/1.31 = 0.76\ m^3h^{-1}$.

Table 87. Reclamation activities, coresponding earth movement ($m^3\ ha^{-1}$) and manual and mechanical labour requirements ($h\ ha^{-1}$) on land unit U2, for a plot of 100 × 100 m.[b]

Reclamation level II					
	Floodwalls[3]	Bunds[4a]	Clearance[5] A	Road construction[6] A	Erosion control[7]
Earth movement:	200	200[8)]		10	38[9]
Labour requirements:					
manual[1)]	135	135	225-430	7	25
mechanical[2)]	8[10)]	2	5-8	—	0.4
Reclamation level III					
	Clearance[11] B	Road construction[12] B	Drainage ditches[13]	Levelling/Terracing[14]	
Earth movement:		40	500	1250	
Labour requirements:					
manual[1)]	400-800	27	500	1440	
mechanical[2)]	10-30	0.4	20[10)]	16	
Reclamation level IV					
	Irrigation ditches [15]				
Earth movement:	500				
Labour requirements:					
manual	500				
mechanical	20[10)]				

[a] Only bunded rice, no erosion control.
[b] Clay is dominant soil texture on this land unit.

1) Labour productivity assumed to be 1.5 $m^3 h^{-1}$ for clay, 3 $m^3 h^{-1}$ for sand, and 1.0 $m^3 h^{-1}$ (clay) or 1.5 $m^3 h^{-1}$ (sand) for excavation of ditches.
2) Labour productivity assumed at 100 $m^3 h^{-1}$ for clay, 140 $m^3 h^{-1}$ for sand, and 25 $m^3 h^{-1}$ for construction of walls and ditches with dragline.
3) Only required in lowlands, length 200 m, 1 m^3 earth movement per m of flood wall
4) Number of required bunds calculated as: 2 × (slope × field length) / (bund height) (Table 85)
5) Slash-and-burn, large obstacles left in the field.
6) Levelling and excavating for dirt path, width 1 m, to a depth of 0.2 m
7) Crops, other than bunded rice, no bunds.
8) Earth movement for bund construction: $0.5 \times (h_b)^2 \times$ field width × number of required bunds
9) Earth movement for erosion control: $0.5 \times (h_r)^2 \times$ field width × number of required ridges
10) Dragline
11) Removing all obstacles
12) Levelling and excavating for dirt road to a depth of 0.2 m, length 50 m ha^{-1}, width 4 m
13) Total length of drainage ditches is assumed $100 (N_t + 1)$, 1 m^3 earth excavated per m of ditch (Table 85)
14) Excavation depth calculated as: (slope × field length) / 2 N_t (Table 85)
Excavation width calculated as: (field length) / 2 N_t (Table 85)
Earth movement for terracing: 0.5 × excavation depth × excavation width × field width × N_t
Labour productivity of excavation and earth movement for terracing is given in Table 86
Moving distance calculated as: 2/3 × field length / N_t
15) Length of irrigation ditches is assumed $100 (N_t + 1)$, 1 m^3 of earth excavated per m of ditch (Table 85)

Table 88. Total manual and mechanical labour requirement (h ha^{-1}), to convert the original situation into one higher reclamation level on the different landunits[a].

Land unit	Reclamation level			
	I to II	I to II (with bunds)	II to III[b]	III to IV[b]
U1 manual	370-570	420-620	1600-2000	400
U1 mechanical	13-16	14-17	36-56	16
U2 manual	390-600	500-710	2370-2770	500
U2 mechanical	13-16	15-18	46-66	20
U3 manual	240-450	300-500	1680-2080	330
U3 mechanical	5-8	6-9	42-62	20
U4 manual	290-500	530-730	2390-2790	530
U4 mechanical	6-9	11-14	60-80	32
U5 manual	380-580	960-1170	3020-3420	730
U5 mechanical	8-11	21-24	76-96	44
U6 manual	390-600	500-710	-	-
U6 mechanical	13-16	15-18	-	-
U7 manual	380-580	-	-	-
U7 mechanical	8-11	-	-	-

\- not relevant

a It is assumed, that clay is the dominant soil texture in the lowlands (landunits U1, U2, U6) and that sandy soils dominate in the uplands (landunits U3, U4, U5, U7).

b Mechanical excavations of ditches are supposed to be done with a dragline.

cleared of tree stumps, termite hills and big trees. Manually that requires another 600 man-hours per hectare, but with the proper machinery the work can be done in about 20 man-hours per hectare. As it is the intention to grow also other crops than bunded rice at Reclamation Level III, the soil has to be properly drained. It is assumed that this is the case when the land is terraced, with 4 terraces per 100 m along the slope. At an average slope of 4% that requires an earth movement of 1250 m^3 ha^{-1} over an average distance of nearly 17 m. The average productivity for digging, loading and transport per wheelbarrow is 1.0 m^3 per man-hour, so the labour requirement is 1250 man-hours per hectare, if done manually. If a bulldozer is used, only 14 man-hours per hectare are needed (Table 86). In addition, it is necessary to construct 500 m of drainage ditch per hectare, one hundred metres along the slope and four times one hunderd metres along the ridges of the terraces. This requires the movement of 500 m^3 of soil, which takes 400 man-hours if done by hand and 20 man-hours with a dragline. At Reclamation Level III, dirt paths need to be replaced by dirt roads with a width of 4 m to allow the use of animal-drawn and mechanical equipment. That requires the movement of only 30 m^3 ha^{-1}, which takes 15 man-hours per hectare, if done by hand and less than 1 man-hour, if a bulldozer is available.

Hence, the upgrading of one hectare of land from Reclamation Level II to Reclamation Level III takes about 2400 man-hours per hectare, if done manually. As most of the work can only be carried out during the growing season, it can hardly be expected that this time can be made available. Therefore unless machinery is available, it is most likely that the farmer has no option but the cultivation of bunded rice at Reclamation Level II.

To upgrade the terraced land at Reclamation Level III to Reclamation Level IV it suffices to add 500 m of irrigation ditch per hectare, which requires the same amount of work as the construction of drainage ditches. This is negligible, compared to the costs of the total infrastructure for irrigation.

A summary of all reclamation activities described in this section, the corresponding earth movement and manual and mechanical labour requirements on Land Unit U2 are given in Table 87. Because clay is assumed to be the dominant soil texture class on this land unit (lowlands), the labour requirements given in Table 87 refer to clay soils only. A summary of the total manual and mechanical labour requirement, for converting the original situation (Reclamation Levels I, II, III) into one reclamation level higher is given in Table 88.

Exercise 96

Calculate earth movement and labour requirement (both manual and mechanical) for the various activities required to obtain Reclamation Level II, III and IV on Land Unit U4 (sandy soil). The information required is summarized in Tables 87 and 88.
