專　論

The Determination of System Capacity and Management Program for Irrigation of Transplanted Rice

水稻灌溉系統容量之決定與整田用水之管理

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中 文 摘 要

水稻灌溉之整田揷秧需水量通常爲 100～200 公厘，其爲灌溉期間之最大需水量。爲供應整田期間之用水，在灌溉系統之規劃及設計，以往採用衆知之慣用公式，決定渠道及抽水容量。該慣用公式係假定整田用水量自整田初期之小水量以直線變化至整田後期之最大用水量，並取其最大値爲渠道或抽水機之容量。實際上，在整田期間甚難按上述假定實施灌溉管理。如採用該公式規劃及設計灌溉系統，不但浪費用水而且增加灌溉系統之投資。本文解析該慣用公式之缺點，並導出新公式，以求整田用水及灌溉系統投資之節省。爲整田期間灌溉管理之方便，試以新公式之圖解方法，俾使迅速求得整田用水量及整田期間各階段之應供水面積。

OBJECTIVES

In the irrigation of transplanted rice, land preparation requires amounts of water varying from 100 to 200mm which is usually the maximum water requirement. In the planning and design of rice irrigation, a conventional formula based on the water supply during land preparation has been used to determine the capacity of the canal or pump. This conventional formula was derived with an assumption that the discharge varies with a straight line from a small amount of water at the beginning to the maximum amount of water at the end of land preparation. The defects in the formula are that the irrigation water can hardly be controlled as assumed and that the maximum discharge as determined will require a large capacity canal or pump. The results are uneconomical use of water and high costs in construction of irrigation systems.

The objectives of this report are:

1. To analyze the conventional formula used for the determination of the capacity of a canal or pump for the irrigation of transplanted rice.
2. To modify the conventional formula.
3. To compare the modified and conventional formula.
4. To provide nomographs for application of the modified formula.

In some regions, including Taiwan, two or more rice crops can be grown each year. In Taiwan the first crop of rice is transplanted from January to March and harvested from May to July. The second crop is transplanted from late June to August and harvested from late September to early December.

Prior to transplanting, the paddy fields are plowed, supplied with water, puddled by harrowing several times, and finally leveled. According to PDAF (3). the purposes of land preparation are:

1, To soften the soil for transplanting.
2. To mix fertilizers and organic composts uniformly into the soil.
3. To prevent excess percolation.
4. To provide favorable conditions for the root growth of young plants.

The writer suggests to use the following formula to determine the puddling water requirement:

$$D_s = \frac{(n - P_v)\, D}{100} + H$$

where

D_s = puddling water requirement, in mm

n = porosity of soil in percent or $100\left(1 - \frac{A_s}{R_s}\right)$ in which As is the apparent density and Rs is the real density of the soil,

P_v = soil moisture content, in percent on volume basis,

D = depth of soil to be saturated (300mm on average), and

H = depth of standing water in mm ranging from 30mm to 50mm.

In practice, the land preparation over an area of paddy field takes a considerable length of time, which ranges from two to four weeks depending on the locality, climatic conditions, varieties, cropping patterns, farm mechanization, and the availability of water and labor.

Following the land preparation of individual fields, seedlings are successively transplanted from the nursery, which is about one twenty-fifth of the size of the transplanted field. The suitable transplanting age of the young plants is 20 to 40 days, depending on the variety and the locality.

The practice of rice transplantation is widely carried out in every country of the Far East. Fukuda and Tsutsui (2), give the advantages of this practice as follows:

1. Rice plants can be grown with less weeds, compared to the direct sowing method, provided that the seedlings are transplanted at the proper time to the well puddled paddy field.

2. Uniform and healthy seedings are produced since concentrated care is provided by the farmers in the nurseries.

3. Damage by birds can be eliminated as the seeds are grown under submergence.

4. The length of time for growth of the second crop can be prolonged, since most paddy fields are kept free until transplantation.

5. The practice acts as a safeguard against the damage which occurs during the initial growing stage, since re-sowing is easily carried out in nurseries and importation of healthy seedlings from nondamaged areas is possible.

The transplanting practice makes Taiwan capable of adopting the intensive-relay cropping system. By interplanting and transplanting, two, three, and even four crops with growing seasons adding up to as much as 14 to 15 months can be grown on a single piece of land each year.

During the time of land preparation and transplanting, a large amount of water is usually required. The maximum water, which is the combination of puddling water requirement for land preparation and the water requirement for transplanted rice fields, occurs in this period if there is no rainfall or the whole area is developed within a very limited period of time. In practice, some formulas are used in Taiwan and Japan for determining the capacity of a canal or pump for transplanted rice.

Conventional formuta used in Taiwan

The formula of PWCB (4) conventionally used for the determination of canal or pump capacity can be written as follows:

$$Q \text{ (in m}^3\text{/day)} = \left(\frac{AD_s}{N} + AD_t\right)\frac{1}{1-L} \quad \cdots\cdots (1)$$

or

$$Q \text{ (in cms)} = \left(\frac{AD_s}{NT} + \frac{AD_t}{T}\right)\frac{1}{1-L} \quad \cdots\cdots (1a)$$

where

Q=canal or pump capacity (maximum discharge),

A=area in m^2 to be irrigated,

D_t=water requirement in meters per day in the transplanted rice field,

D_s=puddling water requirement in meters required for soaking the field

N=period of land preparation, in mumber of days, for the entire area, A,

T=number of seconds in one day, and

L=conveyance loss, in decimals.

Chow (1) gave a revised form of Equation (1) for rotational irrigation as follows:

$$Q = \frac{A}{8.64}\left(\frac{d_s}{P_s} + \frac{d_r}{P_r}\right)\frac{1}{1-L} \quad \cdots\cdots (2)$$

where

Q = the required canal capacity, in cubic meters per second,

A = the irrigated area, in hectares,

d_s = the depth of water, in meters, required for soaking the field,

d_r = the depth of water in meters for each application to the transplanted field,

P_s = the period of soaking the field in days,

P_r = rotation interval. in days, and

L = canal conveyance loss, in decimals.

Formula used in Japan

According to Fukuda and Tsusui (2), daily water requirement for the *xth* day from the beginning of land preparation is:

$$R_x = \frac{10A}{n}\left\{ s + (x-1)\, d \right\} \quad \cdots\cdots (3)$$

and the maximum water requirement in the period is

$$R_{max} = \frac{10A}{n}\left\{ s + (n-1)\, d \right\} \quad \cdots\cdots (4)$$

where

R_x=daily water requirement in cubic meters per day for the *xth* day from the beginning of land preparation,

R_{max}=maximum water requirement in cubic meters per day,

A=area to be puddled, in hectares,

d =unit water requirement (mm/day) in the transplanted field,

s =puddling water depth, in millimeters, and

n =number of days in land preparation.

Analysis of conventional formula

Equation (1) or (la) is derived on the assumptions that the rate at which an area is supplied with puddling water is constant through the whole period of land preparation and that the water requirement for transplanted rice (D_t) is supplied to an area which has been provided with the puddling water, and that the effective rainfal is negligible in the short period of N days.

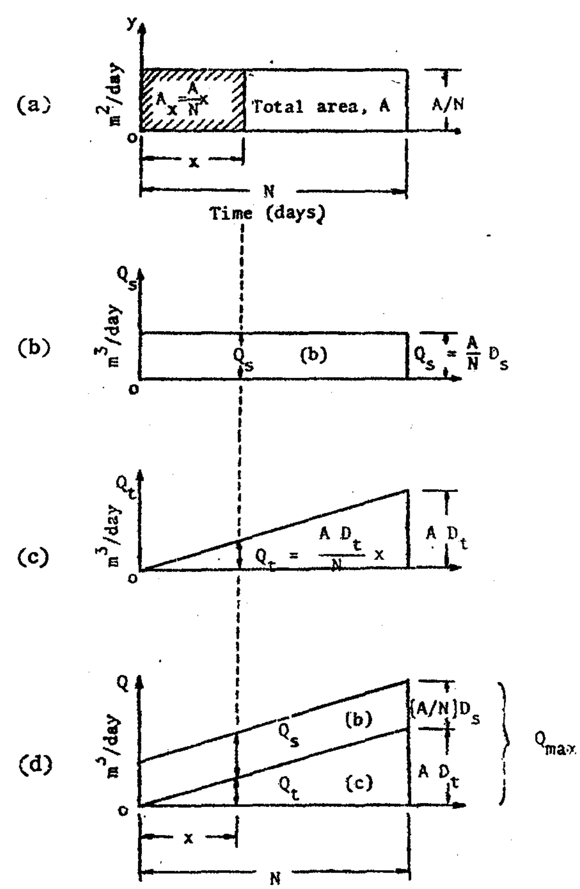


Figure 1 Schematic diagrams of water use in land preparation

Equation (1) can be analyzed with Figure 1. Figure la shows the relationship between time (in days) and the rate at which an area is provided with puddling water, y, which is equal to A/N (in m²/day) through the whole period of land preparation, N.

Figure lb shows the relationship between time and the discharge, Q_s, needed for puddling the field, where $Q_s = yD_s = A/N\ D_s$ (in m^3/day). Figure lc shows the relationship between time and the discharge, Q_t, needed in the transplanted rice field, where $Q_t = A_x D_t = \frac{AD_t}{N} x$ (in m^3/day) at the point of x (in days) from the beginning; and Figure ld shows relationship between time and the total discharge, Q_x(in m^3/day). which is equal to $(Q_s + Q_t)$; i. e.,

$$Q_x = \frac{AD_s}{N} + \frac{AD_t}{N} x \text{(in m}^3\text{/day)}$$

When x=N, the discharge will be maximum. Therefore,

$$Q_{max} = \frac{AD_s}{N} + AD_t \text{ (in m}^3\text{/day)} \qquad (5)$$

If conveyance loss of a canal is considered in addition to Equation (5), Equation (1) can be obtained.

From Figure 1, one can find the defects of the conventional formula as follows:

1. The formula shows that the capacity of a canal or pump is designed for the maximum discharge, Q_{max}, at the end of land preparation, while a small discharge is all that is required at the beginning of the period. Actually, warer is not controlled daily with variable discharges through the period as assumed in the formula.

2. If water is supplied with a constant discharge through the period of land preparation, the discharge is certainly smaller than that of the formula.

Equations (2) and (4) are similar to Equation (1).

Modification of conventional formula

Under a condition that the relationship between time, x. and the rate of land development, y, is a curve, y=f(x), starting from $y = y_0$ when x= O, and ending at $y = y_N$, when x=N with an enclosed area of A as shown in Figure 2, the discharges required for puddling the field and for the transplanted rice at the time, x, will be respectively:

$$Q_s = yD_s$$

$$Q_t = A_x D_t = D_t \int_0^x y dx$$

and the total of Q_s and Q_t will be:

$$Q = y D_s + D_t \int_0^x y\, dx \qquad (6)$$

In order to supply a constant discharge through the whole period of land preparation under the most economical condition for the determination of canal or punp capacity, let Q=constant, and differentiate Equation (6). Therefore,

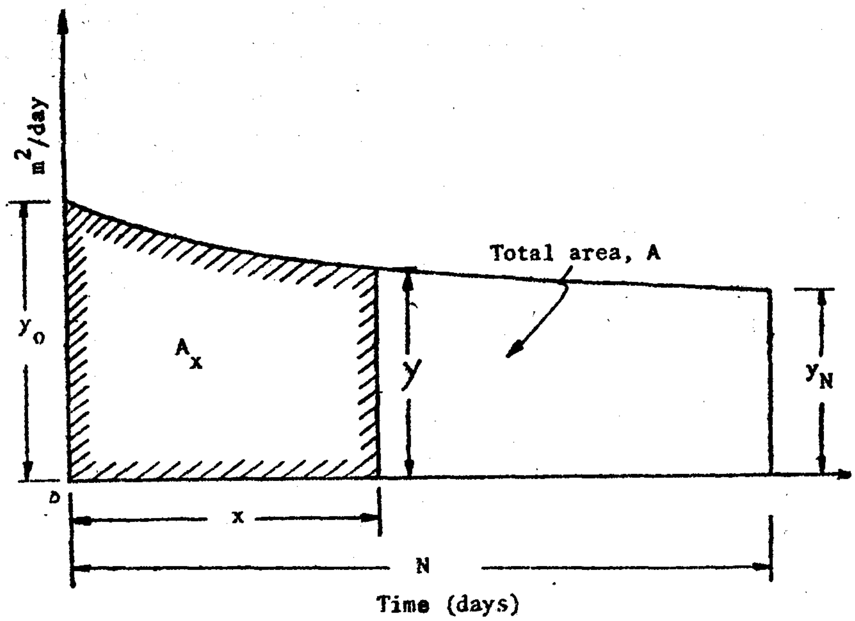
$$O = D_s \frac{dy}{dx} + D_t y$$

or

$$\frac{dy}{dx} = -\frac{D_t}{D_s} y \qquad (7)$$

The above differential Equation (7) is a condition that $(Q_s + Q_t)$ is always equal to a constant discharge. Its solution will be:

$$\int \frac{dy}{y} = -\frac{D_t}{D_s} \int dx + C$$



wher

$$A_x = \int_0^x y\,dx$$

$$A = \int_0^N y\,dx$$

Figure. 2 Schematic diagram for proposed water use in land preparation.

or

$$\log y = -\frac{D_t}{D_s}x + C$$

$$y = e^{(C - D_t x/D_s)} = e^c e^{-(D_t/D_s)x}$$

where

e = the base of natural logarithm = 2.718282...

The constant e^c can be evaluated from the condition that $y = y_0$ at $x = 0$, giving

$$y = y_0 e^{-(D_t/D_s)x} \quad \text{.......... (8)}$$

Because

$$A = \int_0^N y dx,$$

$$A = y_0 \int_0^N e^{-(D_t/D_s)x} dx = y_0 \left. \frac{e^{-(D_t/D_s)x}}{-(D_t/D_s)} \right]_0^N$$

$$A = y_0 \frac{e^{-(D_t/D_s)N} - 1}{-(D_t/D_s)}$$

$$y_0 = \frac{A D_t}{D_s\left(1 - e^{-(D_t/D_s)N}\right)} \quad \text{.......... (9)}$$

If the value of y_0 is substituted into Equation (8), one obtains

$$y = \frac{A D_t e^{-(D_t/D_s)x}}{D_s\left(1-e^{-(D_t/D_s)N}\right)} \quad \cdots\cdots \quad (10)$$

The discharge, Q, is constant for the entire period of land preparation; therefore it is convenient to evaluate Q at x=N. Equations (6) and (10) will be respectively:

$$Q = y_N D_s + A D_t$$

and

$$y_N = \frac{A D_t e^{-(D_t/D_s)N}}{D_s\left(1-e^{-(D_t/D_s)N}\right)} \quad \cdots\cdots \quad (11)$$

Therefore,

$$Q = \frac{A D_t e^{-(D_t/D_s)N}}{1-e^{-(D_t/D_s)N}} + A D_t$$

$$= \frac{AD_t}{1-e^{-(D_t/D_s)N}}$$

If the conveyance loss of the canal is considered, the discharge, Q, will be:

$$Q = \frac{AD_t}{1-e^{-(D_t/D_s)N}} \cdot \frac{1}{1-L} \quad \cdots\cdots \quad (12)$$

Final Formulas

If water conveyance efficiency, E_c, is applied to Equation (12), one obtains the finally modified formula,

$$Q \text{ (in m}^3\text{/day)} = \frac{AD_t}{E_c\left(1-e^{-(D_t/D_s)N}\right)} \quad \cdots\cdots \quad (13)$$

$$Q \text{ (in cms)} = \frac{A_h D_t}{8.64 E_c\left(1-e^{-(D_t/D_s)N}\right)} \quad \cdots\cdots \quad (14)$$

where

A_h = Area in hectares

E_c = decimals instead of percent

In rotational irrigation, D_t will be D_r/P_r in which D_r is the depth of water for each application of rotational irrigation and P_r is the rotation interval in days.

Numerical example and comparison

If the known factors are:

$A = 100$ ha $= 1{,}000{,}000 m^2$

$D_t = 10.5$mm/day $= 0.0105$m/day

$D_s = 180$mm $= 0.18$m

$N = 20$ days

$L = 0.2$ and $E_c = 0.8$

From Equation (13), the required discharge will be:

$$Q = \frac{1{,}000{,}000 \times 0.0105}{0.8\left(1-e^{-\frac{0.0105}{0.18}\times 20}\right)}$$

$$= \frac{10,500}{0.8\left(1-e^{-1.167}\right)}$$

$$=19,070 m^3/day = 0.22 cms$$

From Equation (1), however, the required discharge will be

$$Q=\left(\frac{1,000,000\times 0.18}{20}+1,000,000\times 0.0105\right)\frac{1}{1-0.2}=(9,000+10,500)\frac{1}{0.8}=24,375 m^3 day=$$

0.282cms

The ratio of the above two discharges is about 1.3; i.e., Equation (1) requires about 30 percent of canal/pump capacity more that Equation (13) in this example.

From Equations (9) and (11), the rates of land preparation at the beginning and at the period, respectively are calculated as follows:

$$y_o=\frac{1,000,000\times 0.0105}{0.18\left(1-e^{-\frac{0.0105}{0.18}\times 20}\right)}=\frac{10,500}{0.18\left(1-e^{-1.167}\right)}=84,800 m^2/day=8.48 ha/day$$

$$y_N=y_o\, e^{-\left(\frac{0.0105}{0.18}\times 20\right)}=8.48\times 0.312=2.65 ha/day$$

Nomographs for application

For practical application, canal or pump capacities may be directly obtained from Figure 3, which was developed from Equation (14). The percent, P_x, of area to be supplied with puddling water on the x*th* day from the beginning of land preparation is shown in Figure 4 by using the following equation derived from Equation (10):

$$P_x=\frac{100\, D_t\, e^{-(D_t/D_s)x}}{D_s\left(1-e^{-(D_t/D_s)N}\right)}$$

Conslusion

In actual field practice, during the period of land preparation and transplanting, water flow can hardly be controlled to a discharge that varies with a straight line as assumed in the conventional formula which gives a large discharge at the end of the period. It is, therefore, believed that the conventional equation is not practical. While the newly derived formula gives a constant discharge smaller than that of the conventional one, the smaller capacity results in lower construction cost. Furthermore, the new formula will give a sufficient amount of water as far as the total volume of water given in the period is concerned. It is recommended that Equation (14) be used instead of the conventional one in determination of canal or pump capacity for the irrigation of transplanted rice.

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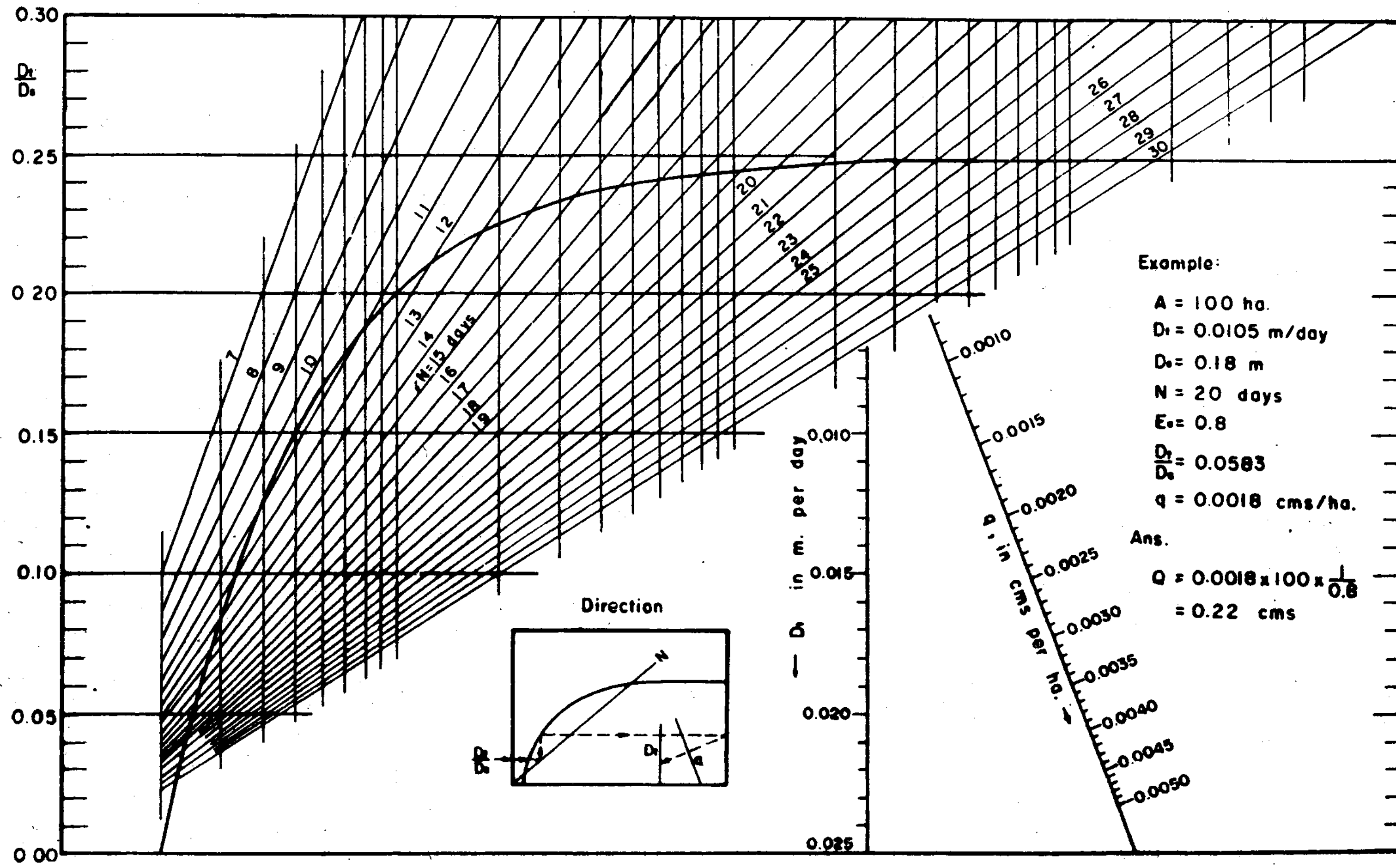

Fig 3 Discharge per hectare for land preparation and transplanting.

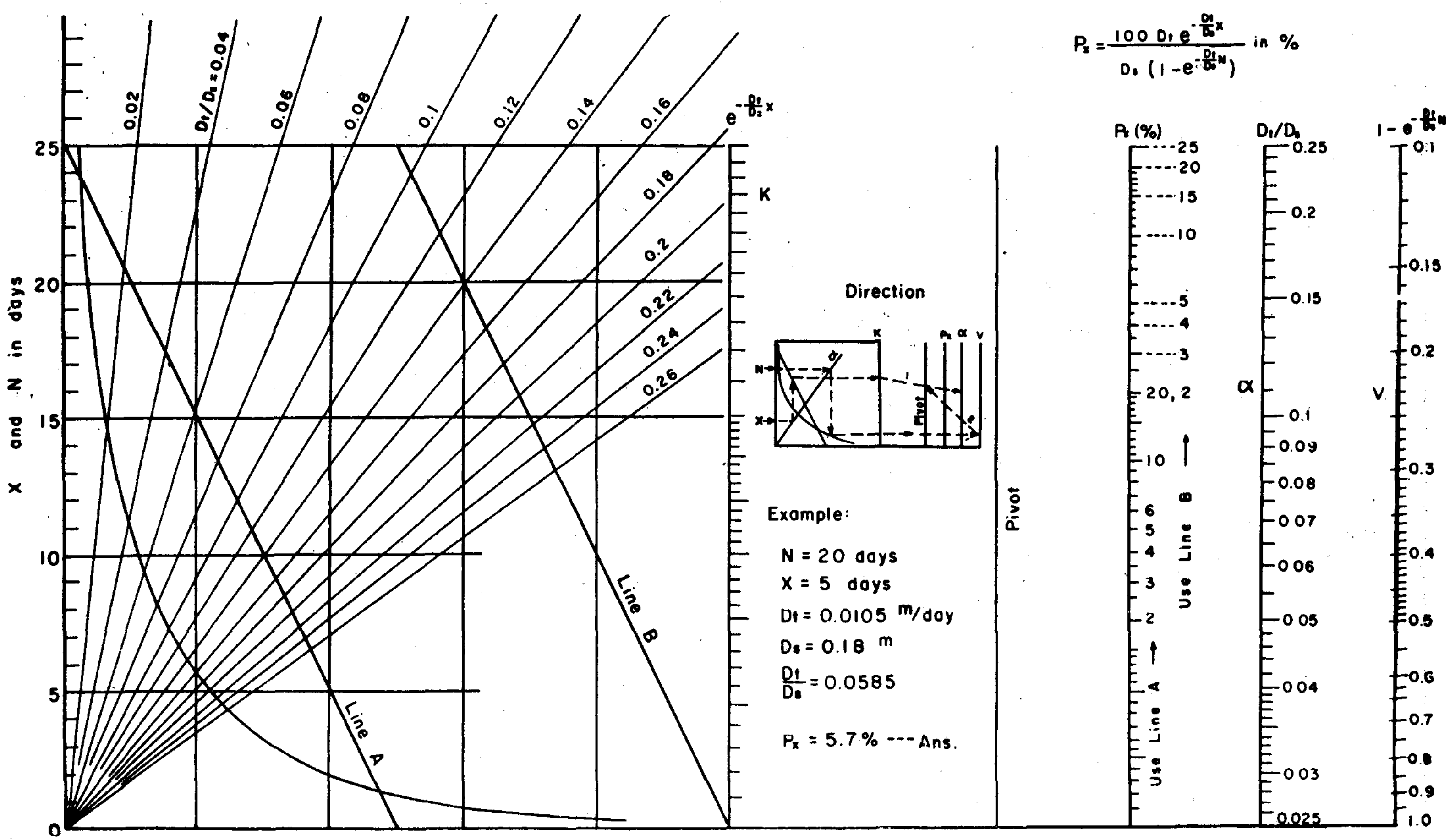

Fig 4 Percentage of area to be supplied with puddling water on the X-th day from the beginning of land preparation.