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A Role of Fertilizer Application to Yield Increase in Central and West African Countries

Akio SUMI and Tadao C. KATAYAMA*
(Laboratory of Tropical Crop and Experimental Farm*)
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Introduction

The authors pointed out in the previous paper[6] that the west and central African regions are, fundamentally or on an average, in possession of some climatic resources, which are nearly equal to rainfall resource in those regions, and larger than the world average. Nevertheless, due to the fact that in those regions the increasing degree in the yielding capacity varying with the amount of climatic resources or rainfall resource was considerably slower, the yielding capacity showing the relative productivity in the arable land was remarkably below the world average. These results suggest that, broadly speaking, the yielding capacity in those regions has been limited not by the lack of climatic resources, but by the extremely low efficiency of the climatic resource-utilization.

Although it goes without saying that the crop production has been strongly affected by the amount of climatic resources, it is not so fixable as the amount of underground resources[9]. That is, it is expected that the relative value of climatic resources will be increased remarkably by the progress of the integrated cultivation techniques, including plant breeding. In fact, according to a trial calculation, the slope of regression line between the productivity index in arable land and the warmth index, a kind of agroclimatic index, is said to have increased about 30% for 35 years, because of the progress of cultivation techniques[9]. Two items are to be suggested by these, the first is that the possibility of increased crop production in those regions will be far from negative and the second is that it is of urgent necessity to make technical revolutions such as the introduction of high yielding varieties, improvements in fertilizer application techniques, and disease-, insect- and weed- controllings.

On the basis of the data that the amount of fertilizer application in those countries was exactly 0.5～20.6% of world average[1], two simple experiments were carried out in order to discuss how the increase in the amount of fertilizer application will be related with the efficient utilization of water resource. This paper summarizes our findings.

Materials and Methods

Experiment 1. The experiment was carried out in the vinyl-plastic hothouse in the Experimental Farm of Faculty of Agriculture, Kagoshima University, from 22 April to 19 June, 1987. Forty eight grains of the sorghum (*Sorghum bicor* (L.) MOENCH, cv. Sorghum-Sudan Hybrid) were sown, on 22 April, in 13 litter seedling culture boxes filled with a uniform soil of 8.15kg of dried soil passed through a sieve of 5mm across. The shoots were harvested on 21 May, once. Twenty five treatments were imposed on the ratoons. On 23 May, as basal dressing, the entire amount of ammonium nitrate, calcium dihydrogenphosphate monohydrate and potassium chloride were applied. Although calcium dihydrogenphosphate monohydrate and potassium chloride were applied at 0.84 g/pot of P_2O_5 and K_2O basis through the whole treatments, the amount of ammonium nitrate application was parceled out into the five steps, that is, 0, 0.42, 0.84, 1.68, and 3.37 g/pot of N_2 basis, in accordance with those treatments. The soil moisture treatments were also parceled out into the five steps, that is, 16, 24, 32, 40 and 48%. Soil moisture control was carried out by a gravimetric method from 29 May to 19 June and the amount of water supplied in order to keep the soil moisture condition constant was sprinkled on the soil surface every day. However, because the soil moisture condition changed gradually with the increases in evapotranspiration and plant weight, the soil moisture ratio used in this paper was the average value during the soil moisture treatments. The outline of treatments used is shown in Table 1.

On 19 June, forty eight plants with no replications were harvested from each plot. These plants were separated into leaf blades, leaf sheaths and culms, and roots, and were dried at 80℃ for 72 hours to get dry weight.

Experiment 2. The experiment was carried out in the Experimental Farm of the Faculty of Agriculture, Kagoshima University, from 22 April to 30 September, 1987. Seeds of the rice (*Oryza sativa* L. cv Nipponbare) were sown on 22 April. Seedlings of about 3rd-leaf stage were transplanted in 1 /5,000 a of Wagner's pot at the rate of two plants per one pot on 19 May, and were made to be grown out in the fields until heading stage (10 August). Ten treatments were imposed on the plants. And five pots were used per each treatment. Although the basal and top dressings were carried out at the rate of 1.5g/pot of compound fertilizer (8-8-8) in all the treatments on 19 May and on 25 June, respectively, the amount of ear manuring was parceled out into the two steps, that is, 0 and 6.0 g/pot of compound fertilizer, and it was carried out on 2 August (8 days before heading stage). At the heading stage, total dry matter weight was 38.5 g/pot in no application plot and 37.6 g/pot in application plot, respectively, and chlorophyll content was 35.5 in no application plot and 41.5 in application plot, on the reading value of SPAD, respectively. On 10 August, all the pots were carried into a vinyl hothouse. And, during 51 days, from the day after heading to 30 September, the irrigation treatments which were parceled out into the five steps, that is, 100, 200, 300, 400 and 600 ml/pot•day were carried out, and irrigation water was sprinkled on the soil surface every day.

On 30 September, 51 days after the heading stage, five hills were harvested from each plot. These plants were separated into leaf blades, leaf sheaths and culms, panicles and roots, and were dried at 80℃ for 72 hours to get dry weight.

Table 1. Outline of Experiment 1.

f \ g	A	B	C	D	E
1	14.1 \ 0	13.7 \ 0.42	13.6 \ 0.84	13.7 \ 1.68	13.6 \ 3.37
2	20.7 \ 0	19.8 \ 0.42	18.8 \ 0.84	18.7 \ 1.68	18.9 \ 3.37
3	28.2 \ 0	26.7 \ 0.42	25.4 \ 0.84	25.0 \ 1.68	25.0 \ 3.37
4	36.0 \ 0	34.4 \ 0.42	33.1 \ 0.84	31.8 \ 1.68	31.6 \ 3.37
5	44.2 \ 0	42.2 \ 0.42	40.3 \ 0.84	38.6 \ 1.68	37.9 \ 3.37

Note : f and g indicate the mean soil moisture ratio (%) during the treatments and the amount of nitrogen application (g/pot), respectively.

Results

Fig. 1 shows the relationship between the available soil moisture ratio and the increased total dry matter weight, and it also shows how the quantitative relationship between the two changes with the amount of nitrogen application (Experiment 1). Although the increased total dry matter weight in sorghum plants tended to increase with an increase in the available soil moisture ratio in all the nitrogen application plots, the quantitative response varied greatly, depending on the amount of nitrogen application. That is, it was observed that the promotive effect of soil moisture increase upon growth increment was a little displayed in no application plot, and that although the increased total dry matter weight under dry conditions, less than 10% in the available soil moisture ratio, tended to be greater in 0.84g/pot of application plot than in 3.37g/pot of application plot, the latter was decidedly superior to the former under moist conditions. Fig. 2 shows the relationships between the irrigation intensity and the total dry matter weight, and between that and the panicle dry weight at the time of harvesting (Experiment 2). Although both total and panicle dry weights increased with an increase in irrigation intensity, the quantitative relationship between these two varied, in common with the result in Experiment 1, depending on the amount of compound fertilizer application.

Fig. 3 shows how the ratio of growth increment, in each nitrogen application plot, to that in 1.68g/pot application plot under arbitrary soil moisture condition changes with the available soil moisture ratio (Experiment 1). Fig. 4 shows the relationship between the irrigation intensity and the ratio, of total or panicle dry weight in no ear manuring plot, to that in ear manuring plot (Experiment 2). As a result, it was observed that the ratios decreased or increased with an increase in the available soil moisture ratio or in irrigation intensity, in the case that the amount of fertilizer application in each plot was less or greater than that in standard plot, respectively, and that it was related directly in *log-log* scale with the available soil moisture ratio or irrigation intensity. All the

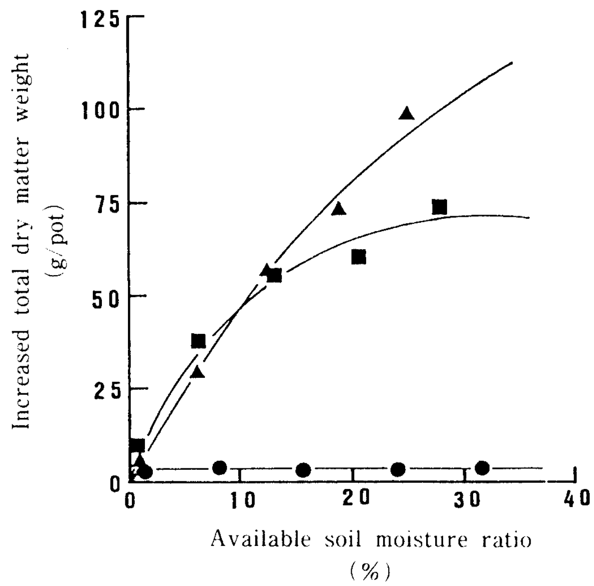

Fig. 1. The effect of nitrogen application upon the quantitative relationship between the available soil moisture ratio and the increased total dry matter weight (Experiment 1).
●, ■ and ▲ indicate the increased total dry weight in 0, 0.84, and 3.37 g/pot of nitrogen application plots, respectively.

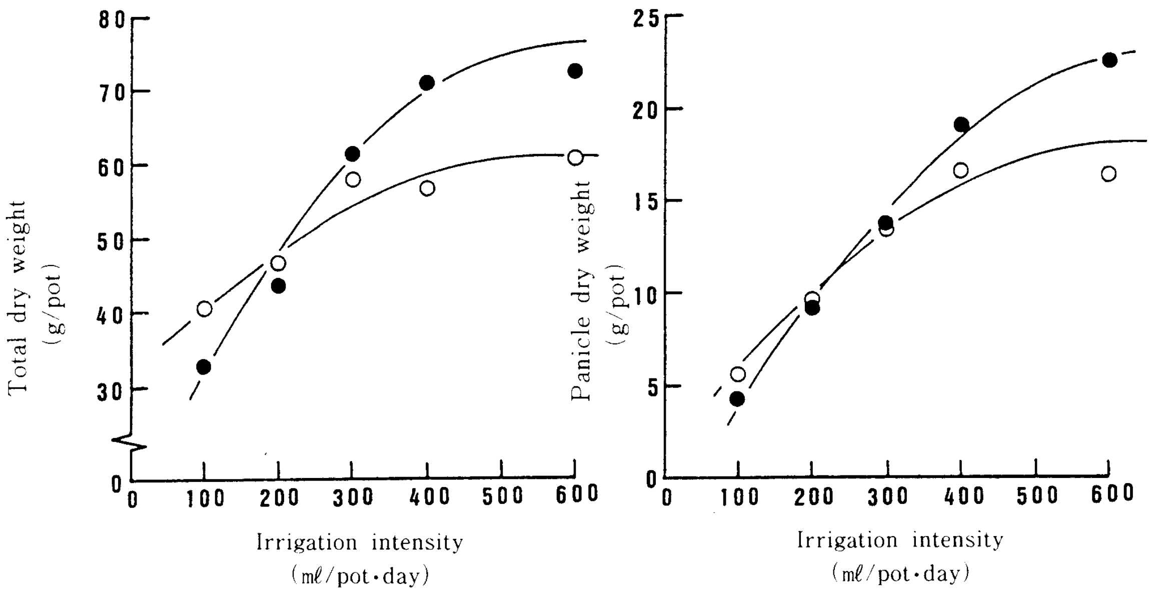

Fig. 2. The effect of ear manuring upon the quantitative relationship between irrigation intensity and total and panicle dry weights at the time of harvesting (Experiment 2).
○ and ● indicate the total and panicle dry weights in 0 and 6.0 g/pot of compound fertilizer (8-8-8) application plots, respectively.

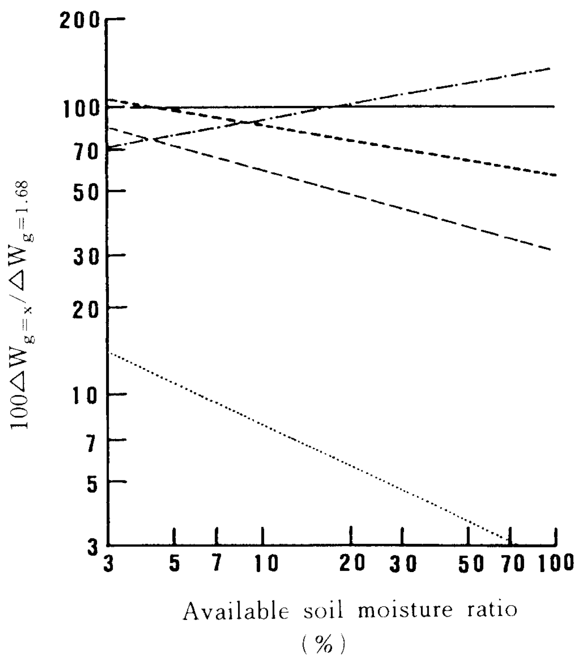

Fig. 3. Relationship between the available soil moisture ratio and the ratio of growth increment in each nitrogen application plot to that in 1.68 g/pot application plot ($100\triangle W_{g=x}/\triangle W_{g=1.68}$) (Experiment 1).
········, ------, ------, ———, and -·-·-·- indicate the ratios of 0, 0.42, 0.84, 1.68 and 3.37 g/pot of nitrogen application plots, respectively.

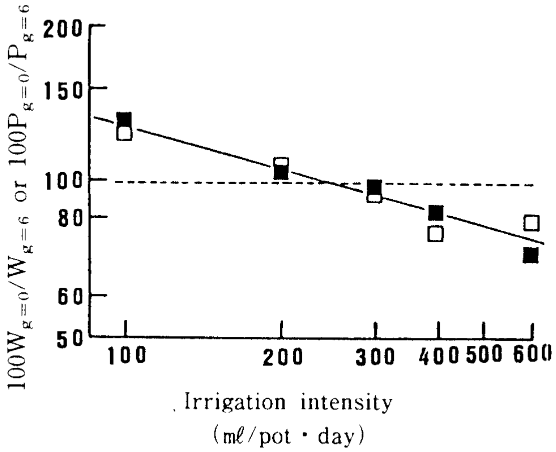

Fig. 4. Relationship between irrigation intensity and the ratios of total and panicle dry weights in no ear manuring plot to those in ear manuring plot ($100W_{g=0}/W_{g=6}$ or $100P_{g=0}/P_{g=6}$) (Experiment 2). □ and ■ indicate the ratio of total and panicle dry weights, respectively.

relationships mentioned above could be expressed by the following general equation :

$$Y = \alpha X^{\beta} \qquad \text{Eq. (1)}$$

where Y is the ratio between growth increments in the two fertilizer application plots under arbitrary soil moisture condition or irrigation intensity, X is the amount of water resource, such as the available soil moisture ratio and irrigation intensity, α and β are invariables varying with the amount of fertilizer application, respectively. In this equation, the authors regarded Y as a kind of efficiency of the water resource-utilization. On the assumption that α and β in 1.68 g/pot application plot are 100 and 0, respectively, the relationships between α and β, and the amount of effective nitogen application (the amount of nitrogen application + nitrogen content in the soil) are shown in Fig. 5 (Experiment 1). Between α and the amount of effective nitrogen application was observed an optimum curvilinear relationship. The result also showed that the optimum amount of effective nitrogen application was at remarkably low level (about 0.45kg/a), and that α under optimum condition was beyond 100 (Fig. 5a). On the other hand, β changed from negative, via zero, to positive with an increase in the amount of effective nitrogen application (Fig. 5b).

Discussion

Lieth[3] found that the net primary productivity (NPP) of natural vegetation can be expressed as functions of the annual mean air temperature and the annual amount of precipitation, respectively. Seino and Uchijima[5] succeeded in relating it with the radiation dry index. Those equations which are called "Miami model" and "Chikugo model", respectively, suggest that NPP of natural vegetation has been strongly affected by different climatic elements, such as temperature, solar radiation and the amount of precipitation before other factors.

Matsuda *et al.*[4] assumed that NPP in arable land would be as large as, or 0.81 times as large as that of natural vegetation under heavy manuring cultivation or the others, respectively. On the basis of the data in various places of Japan[2], the authors found that NPP in arable land increases directly with an increase in NPP estimated by Chikugo model, and that the ratio of the former to the latter is kept at about 0.8 on calorie basis (unshown). This result nearly agrees with Matsuda's.

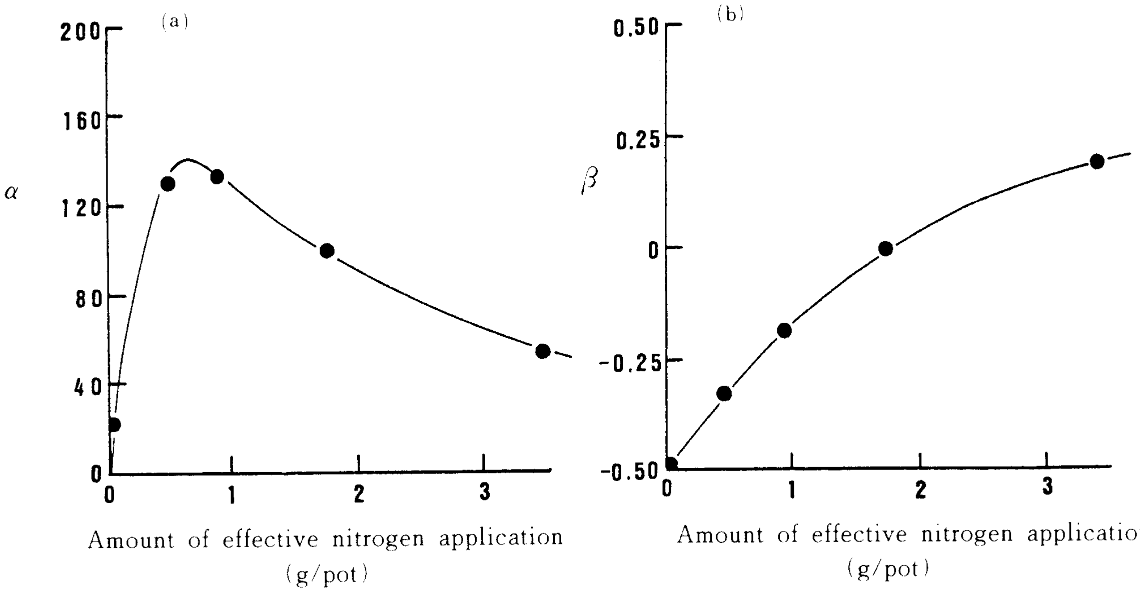

Fig. 5. Relationships between the amount of effective nitrogen application*1 and α and β in Eq.(1) (Experiment 1).

*1 : The amount of effective nitrogen application indicates the total of the amount of nitrogen application and nitrogen content in the soil assessed by Balmukand's method.

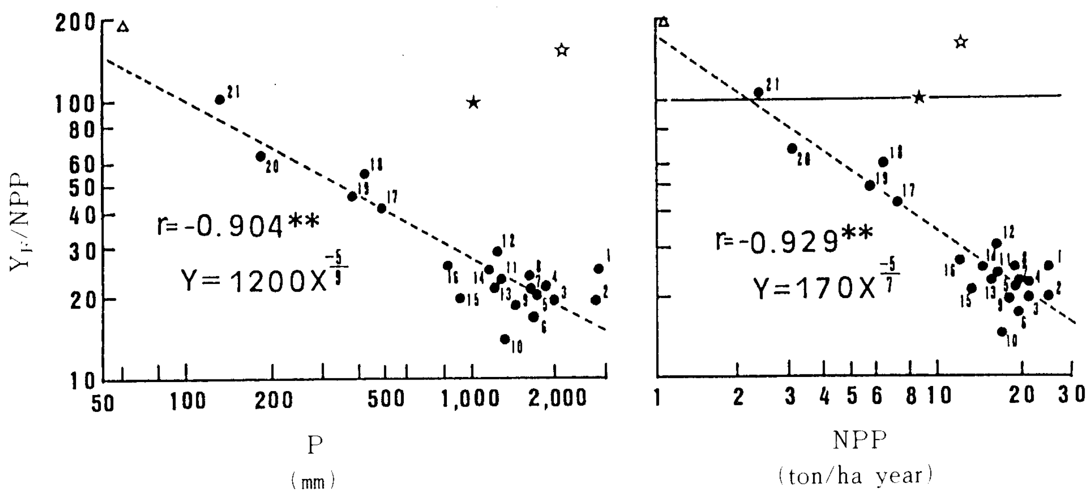

Fig. 6. Relationships between the average annual amount of precipitation (P) and net primary productivity (NPP), and the ratio of yielding capacity index of food crops (Y_F) to net primary productivity (NPP) (Y_F/NPP ratio). Y_F/NPP ratio in each country was indicated to regard the world average as 100[6].
1 : Sierra Leone, 2 : Liberia, 3 : Guinea, 4 : Gabon, 5 : Cameroon, 6 : Guinea Bissau, 7 : Congo, 8 : Zaire, 9 : Ivory Coast, 10 : Cent. Afr. Rep., 11 : Ghana, 12 : Togo, 13 : Nigeria, 14 : Benin, 15 : Burkina Faso, 16 : Senegambia, 17 : Sudan, 18 : Mali, 19 : Chad, 20 : Niger, 21 : Mauritania, △ : Libya, ☆ : Japan, ★ : The world average
Y and X indicate Y_F/NPP ratio and P or NPP, respectively. And, r and ** indicate correlation coefficient and that r was significant at 1% level, respectively.

However, the authors also found that such a conversion factor was little significant in the west and central African regions, because the ratio of yielding capacity index of food crops to NPP estimated by Miami model (Y_F/NPP ratio) decreased directly in *log-log* scale with an increase in NPP or in the annual amount of precipitation in those countries, and because Y_F/NPP ratios in those regions were on the whole below the world average (Fig. 6)[6]. This suggests that the ratio of NPP in arable land to NPP of natural vegetation isn't always kept constant, in other words, that each region or each country has its own ratio. And, it also suggests that NPP in arable land varies greatly, depending not only on climatic elements but also on soil fertility, the kind of crop, and cultivation techniques, such as fertilizer application and weed-, insect- and disease- controllings, as well as that the low productivity in central and west African countries may depend rather on the imperfection of the latter than the former.

It is a common knowledge that the natural vegetations, in particular, mature forest, are well stocked with soil nutrients, such as nitrogen, phosphorus, potassium, calcium and magnesium *etc*., though the amount of those vary greatly, depending on the type of vegetation[12]. Therefore, it is assumed that NPP of natural vegetation may be roughly equivalent to the potential productivity under a climatic condition. Compared with natural vegetation, it has been pointed out that the nutrient status in arable land takes a gradual turn for the worse, because of the removal in crops and leaching and others which are to be brought forth during the cropping period[12]. In particular, the leaching loss increases with an increase in the amount of precipitation. On the other hand, according to FAO fertilizer yearbook[1], the fertilizer application has been carried out a little in those regions. On the basis of informations mentioned above, the authors supposed that the poor nutrient status in those arable land kept the quantitative response of its NPP to the climatic resources considerably slower. On the other hand, from climatological, ecological and agronomical points of view, it has been thinkable that NPP in west and central African countries is limited strongly by the amount of water resource[10,11]. Consequently, to prove the hypothesis mentioned above is nearly equal to prove the fact that the quantitative response of plant growth to the amount of water resource varies in accordance with the nutrient status in soil.

In fact, it was observed in Fig. 1 and Fig. 2 that the quantitative responses of growth increments in sorghum and rice plants to the soil moisture ratio and the irrigation intensity varied greatly, depending on the amount of applied fertilizer, respectively. This accords with the previous results[7,8]. In addition, it was also observed that although the great amount of fertilizer application hastened the plant growth under wet condition, it checked the plant growth under arid condition. Such a response was observed in both vegetative and reproductive periods. Judging from the fact that the negative effect of fertilizer application under arid condition was rather inconspicuous in any fertilizer other than nitrogen, it may be a peculiar response to nitrogen.

Fig. 3 and Fig. 4 showed that the ratio between growth increments in the two sorts of fertilizer application-plots changed directly in *log-log* scale with soil moisture ratio and irrigation intensity, and that it decreased or increased when the amount of fertilizer application in each plot was smaller or larger than that in the standard plot, respectively. The relationship has a strong resemblance to the result in Fig. 6. Therefore, it can reasonably be imagined that the negative correlationship between the Y_F/NPP ratio, and the annual amount of precipitation and NPP observed in west and central African regions may be molded partly by the poor nutrient status in those arable lands.

It is thinkable that α and β in Eq. (1) represent the efficiency of water resource-utilization (Y), under arid and wet conditions, respectively, because α shows Y in $X=1$, and because β decides the vector of Y with an increase in the amount of water resource. On the basis of the results given in Fig. 5, we'll try to discuss a bit the role of fertilizer application to the yield increase in those regions as in the following. In Fig. 6, Mauritania and Libya, where the greater part of the countries has been situated on the Sahara Desert, showed a larger Y_F/NPP ratio than the world average, though the fertilizer application has been carried out a little in those two countries as well as in other west and central African countries. Judging from the results that α showed the maximum value at low nitrogen level, and that α at optimum level was beyond 100, it is assumed that no- or less-fertilizer application under dry condition may act even positively on the efficiency of water resource-utilization, by contraries. The larger Y_F/NPP ratio in Mauritania and Libya may be ascribed to the mechanism mentioned above. In addition, judging from the result in Fig. 5a, it is assumed that it may be difficult and even dangerous to increase the yielding capacity in dry countries by means of the increase in the amount of fertilizer application. Therefore, it is of first necessity for the drier countries to make plans which will remedy the lack of water resource. And, it is expected that the fertilizer application will be secondarily necessary for the efficient utilization of the exploited water resource.

In Fig. 6, Japan, a country of much rain, showed a larger Y_F/NPP ratio than the world average, in spite of fact that the Y_F/NPP ratio in west and central African countries decreased with an increase in the annual amount of precipitation. This inscrutable phenomenon may be explained well by the use of the result in Fig. 5b. That is, judging from the result that once the amount of fertilizer application in each plot became greater than that in standard plot, β varied from negative to possitive, it is expected that the great amount of fertilizer application in Japan, which arrived at greater than 4 times of the world average, would increase the efficiency of water resource-utilization through β. Consequently, it may reasonably be imagined that the increase in the amount of fertilizer application is going to be linked up with the increasing of the yielding capacity in wetter countries by leaps and bounds.

Summary

In order to examine how the increase in the amount of fertilizer application will be related with the efficient utilization of water resource, two simple experiments were carried out. In addition, on the basis of the result, a role of fertilizer application to the yield-increasing in west and central African countries was discussed.

The main results obtained were summarized as follows :

1. The quantitative response of crop growth to the amount of water resource varied greatly, depending on the amount of fertilizer application (Figs. 1 and 2).

2. The ratio between growth increments in the two fertilizer application-plots was related directly in *log-log* scale with the amount of water resource (Figs. 3 and 4). The relationship could be established by the following equation :

$$Y = \alpha X^{\beta} \qquad \text{Eq. (1)}$$

where Y is the efficiency of water resource-utilization which is expressed by the ratio between growth increments in the two fertilizer application-plots under arbitrary water condition. X is the amount of water resource, and α and β are invariables varying with the amount of fertilizer application, respectively.

3. It was observed that there was an optimum curvilinear relationship between α which represents Y under dry condition and the amount of effective nitrogen application, and that the

nitrogen level when α showed a maximum value was considerably low (Fig. 5a). This result suggests that except for extremely infertile land, no- or less- fertilizer application under dry condition may act even positively on the efficiency of water resource-utilization.

4. β which represents Y under wet condition increased from negative, via zero, to positive with an increase in the amount of effective nitrogen application (Fig. 5b). This result suggests that in the wetter countries, the increase in the amount of fertilizer application may be linked up directly with the increasing of the efficiency of water resource-utilization.

5. From the above mentioned results, it was concluded that a negative correlationship between the efficiency of water resource-utilization and the amount of water resource in west and central African countries may depend partly on the poor nutrient status in their arable lands, and that a role of fertilizer application to the yield-increasing in those regions will vary greatly, depending on the amount of water resource in each country.

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