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Dynamics of soil physical and chemical properties within horizontal ridges-organic fertilizer applied potato land

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Dynamics of soil physical and chemical properties within horizontal ridges-organic fertilizer applied potato land

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Abstract. Although the horizontal (contour) ridge has been shown to be significantly effective in reducing erosion within potato land in our previous study, it tends to enhance waterlogged in the soil by which the productivity of crop may be decreased. Beside the availability of organic materials, the dimension of ridge may also affect the waterlogged. However, their impact on the soil properties have been yet less paid attention. This study was aimed to identify the effect of horizontal ridges dimensions on soil physical and chemical properties over organic fertilizer applied potato land. Totally 9 potato plots of 3x3 m^2 were prepared in Serang village, Purbalingga with three different dimensions and replications of the horizontal ridges: 30x 30x30 cm^3 (HR30), 30x40x30 cm^3 (HR40), and 30x50x30 cm^3 (HR50). Petroganik (C-org: 12.5%, C/N ratio: 10-25) fertilizer of 20 ton ha^{-1} was applied into these plots. Soil samples were collected from each plot at 0, 8, 35, 71, and 91 days after planting using 100-cc ring samplers. The physical (volumetric water content, dry bulk density, permeability) and chemical (total-N, total-P) properties of soil were then analyzed in laboratorium using gravimetric and Kjeldahl-Colorimetric method, respectively. The results showed that the soil volumetric water content and dry bulk density increased with increasing the ridges dimensions, of which the highest values of 0.450 cm^3cm^{-3} and 0.730 gcm^{-3} each were found in HR50. Conversely, the soil permeability decreased with increasing the ridges dimensions, of which the highest value of 0.027 cms^{-1} was encountered in HR30. The soil total-N and total-P contents were slightly fluctuated, of which the highest values of 4.111 and 2.213 $tonha^{-1}$ each were seen in HR40. Thus, the horizontal ridge with 40 cm-width might be the most suitable for the organic potato cultivation.

Keywords: Horizontal ridge dimension, organic fertilizer, potato land, soil properties dynamics, waterlogged condition

1. Introduction

Potato has been known as an economically promising commodity in over the world. In tropical region, the crop is usually cultivated in highland areas using vertical (slopping) ridge system with intensive chemical fertilizers and pesticides applications [1]. Such practices, however, may accelerate land and environment degradation. As reported by [2] application of the vertical ridge system on potato lands at the upper stream of Serayu watershed, Central Java, Indonesia has been found to cause severe runoff and soil losses, i.e., 1,358 – 1,435 m^3 ha^{-1} $year^{-1}$ and 56.24 – 145.75 ton ha^{-1} $year^{-1}$, respectively. Furthermore, this also has contributed to sedimentation at Serayu river about 4.3 million m^3 $year^{-1}$ and water contaminated about 100 mg L^{-1} COD and 16.50 mg L^{-1} BOD [3].

Instead of the vertical ridge system, the horizontal (contour) system has been introduced for potato lands [2]. The latter has been found to be significantly effective in reducing runoff and soil losses, i.e., 17 – 34 % and 31 – 73 %, respectively, compared to the former [4]. Nevertheless, less crop yield was noticed, in which the horizontal ridge system might decrease crop productivity about 12% [1] and 23% [2] in rainy season. This was owed to the possible water logging nearby the ridges that might alter soil aeration and drainage conditions [5,6,26].

On the other hand, organic fertilizer is well-known as soil amendments and usually applied to improve the soil physical and chemical properties. The organic fertilizer may enhance water retention, aeration status, and nutrients available for plant [7,23]. Besides, dimension of ridge may affect the soil water content and movement [8,9], hence the waterlogging within the ridge.

Nevertheless, a potential of the organic fertilizer and ridge dimension to overcoming the entailing problems of the possible occurring waterlogging upon the horizontal-ridge system has yet been paid less attention. Accordingly, this study aimed to clarify efficacy of the organic fertilizer and ridge dimensions on the improvement of soil physical and chemical properties over horizontal-ridge system of potato land. The results were then expected to have significant impact on improving potato crop productivity as well as maintaining land and environmental conservation.

2. Materials and Method

2.1. Land preparation

The research site was located at Serang agricultural highland in Central Java province of Indonesia (7°14’31’’ S, 109°16’50’’E) with a typical soil of Andisol (Table 1). A horizontal-ridge system was developed over 9 targeted plots of 3 x 3 m^2 each (Fig. 1B) and varied within various dimensions, i.e. 30 x 30 x 30 cm^3 (HR30), 30 x 40 x 30 cm^3 (HR40), and 30 x 50 x 30 cm^3 (HR50) (Fig. 1A). Upon these plots, organic fertilizer (Petroganik, a local commercial product: 12.5% C-organic, 10-25 C/N ratio) was applied with the rate set for 20 ton ha^{-1} in order to meet equivalent rate of NPK with those of the inorganic fertilizer usually used. Of the each plot, 1 m height plastic sheet, of which 20 cm was embedded into the field, was vertically installed along the plot edges.

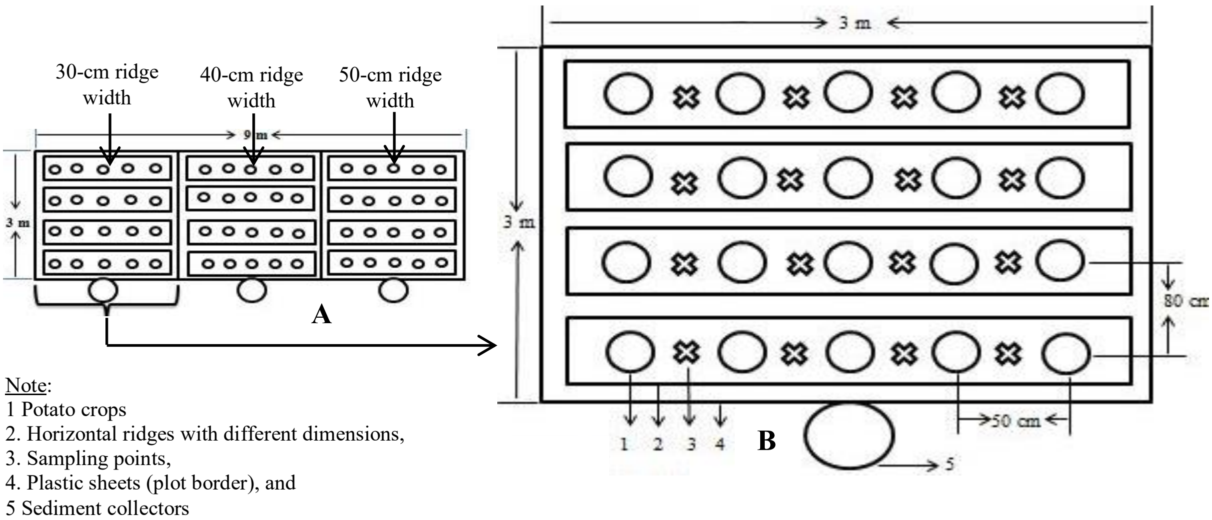

Figure 1. Schematic diagram of experimental plot.

Table 1. Physical and chemical properties of Serang’s Andisol soil

Parameter	**Dimension**	**Value**
Texture		*Loam*
Sand	g g^{-1}	37.44
Silt	g g^{-1}	48.18
Clay	g g^{-1}	14.38
Filed capacity	%	44.07
Permanent wilting point	%	19.83
C-organic	%	5.60
pH		4.96
Total-N (Available-N)	% (ppm)	0.52 (57.16)
Total-P (Available-P)	% (ppm)	0.49 (0.61)

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2.2. Soil sampling and measurement

Undisturbed soil samples at 10, 20, and 30 cm depth were taken nearby the horizontal ridges of each plot using 100 cm^3 core samples. The samples were weighed to determine soil wet-bulk density (ρ_t) and then water saturated for saturated hydraulic conductivity (K_S) measurement using falling head method. The samples were finally oven-dried at 105 ^oC for 24 hours to determine soil mass-wetness (w) and dry-bulk density (ρ_b), by which the volumetric-water content (θ) could be calculated from.

The disturbed soil samples were also taken from the similar locations at the same depth and time as the undisturbed soil samples collection. The samples were analyzed to determine soil total-nitrogen (TN) and total-phosphorus (TP) using Kjeldahl and Colorimetry, respectively.

2.3. Data analysis

The ρ_t, w, ρ_b, and θ were calculated using the following equations, respectively.

$$\rho_t = \frac{M_t}{V_t} \quad (1)$$

$$w = \frac{M_t - M_s}{M_s} \quad (2)$$

$$\rho_b = \frac{M_s}{V_t} \quad (3)$$

$$\theta = \rho_b w \quad (4)$$

Where, M_t is the total mass of soil sample (g), M_s is the dry mass of soil sample (g), V_t is the total volume of soil sample (cm^3).

The K_s was calculated using the following equation.

$$K_s = \frac{2.3aL}{A\Delta t} log \frac{H_1}{H_2} \quad (5)$$

Where, a is the cross-sectional area of inputted water pipe, L is the height of soil sample, A is the cross-sectional area of soil sample, and Δt is the time lag between H_1 (upper level of inputted water) and H_2 (lower level of inputted water).

The soil physical (ρ_t, w, ρ_b, θ, and K_s) and chemical properties (TN and TP) of each ridge dimension (plot) and sample location were averaged and plotted graphically. Both properties were correlated one to another to analyze their correspondences as well as to find most appropriate treatment for sustainable cultivation in tropical region.

3. Results and Discussion

3.1. Soil volumetric-water content (θ)

As shown in Fig. 2A, the average θ values within the horizontal ridges-organic-fertilizer applied potato land tended to increase throughout a cultivation period. The highest θ values of 0.48 – 0.51 cm^3 cm^{-3} was reached at 71 days after planting (DAP), while the lowest θ values of 0.34 – 0.41 cm^3 cm^{-3} was encountered at 35 DAP, regardless ridge dimensions. This was presumably related to rainfall event, in which the θ values increased as the rainfall rates increased and vice versa [10,11]. Besides, the high silt content and organic matter in typical *Loamy* soil observed might also contribute to increasing soil water-holding capacity [12,13].

Among three ridge dimensions applied, the 50-cm ridge width had highest θ value, followed by the 40-cm and 30-cm ridge widths, i.e., 0.45, 0.41, and 0.40 cm^3 cm^{-3}, respectively. (Fig. 2B). This indicated that increasing the ridge dimensions might enhance water entrapment or waterlogged within ridge profile [14]. However, these θ values were considerably similar, since their differences were less than 5 % [15].

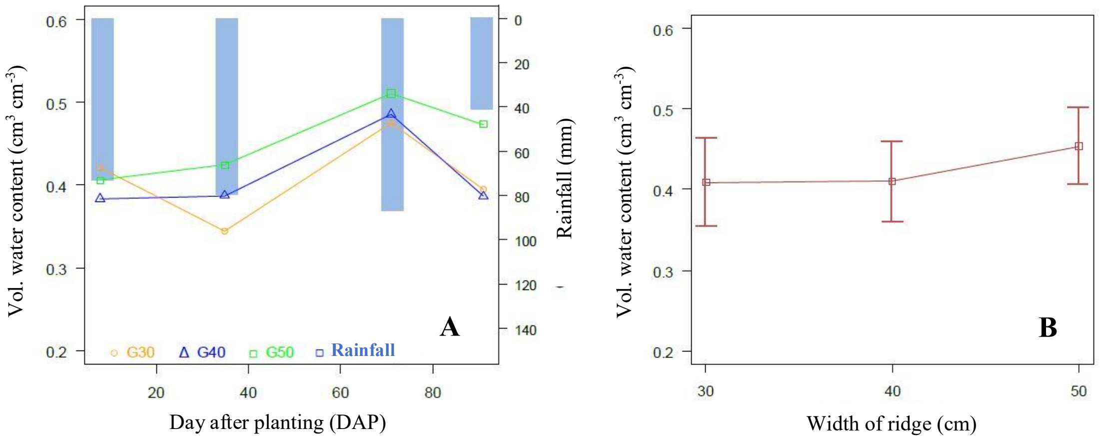

Figure 2. Soil volumetric-water content within various dimensions of the horizontal ridges.

3.2. *Soil dry-bulk density (ρ_b)*

There was a tendency for the average ρ_b values within the horizontal ridges-organic-fertilizer applied potato land to decrease over a cultivation period (Fig. 3A). The highest and lowest ρ_b values were found at 8 and 91 DAP, i.e., 0.74 – 0.78 and 0.59 – 0.66 g cm^{-3}, respectively. The rainfall event was presumably affected the ρ_b, in which higher rainfall rates might increase the ρ_b values thought soil particles detachment and pore clogging [16,24]. Decreasing the ρ_b values might be also affected by the crop roots development, by which the soil aggregation or porosity might be improved [17].

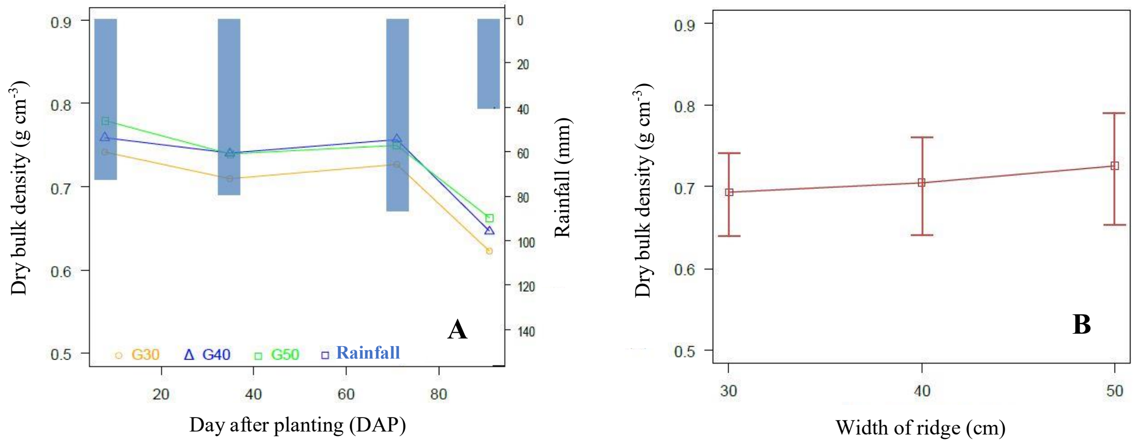

Figure 3. Soil dry-bulk density within various dimensions of the horizontal ridges.

The horizontal ridge with 50-cm width had highest ρ_b compared to that with 40-cm and 30-cm widths, in which their values were 0.73, 0.71, and 0.69 g cm^{-3}, respectively (Fig. 3B), although the differences were considerably insignificant [15]. Higher the ρ_b value as the ridge become wider was presumably related to higher the corresponded θ value, wider the ridge, more the water entrapped and denser the soil. This was related to the soil particle dispersion and pore clogging caused by waterlogged phenomena [12]. Besides, the less availability of soil organic matter might corroborate the results [17].

3.3. *Soil saturated-hydraulic conductivity (K_s)*

The average K_s values within the horizontal ridges-organic-fertilizer applied potato land tended to fluctuate throughout a cultivation period (Fig. 4A). The highest K_s values of 0.032 – 0.035 cm s^{-1} were encountered at 35 DAP, while the lowest K_s values of 0.013 – 0.015 cm s^{-1} were found at 71 DAP.

These K_s values corresponded with the θ and ρ_b values, in which higher the K_s, higher the θ and lower the ρ_b [12,19,20].

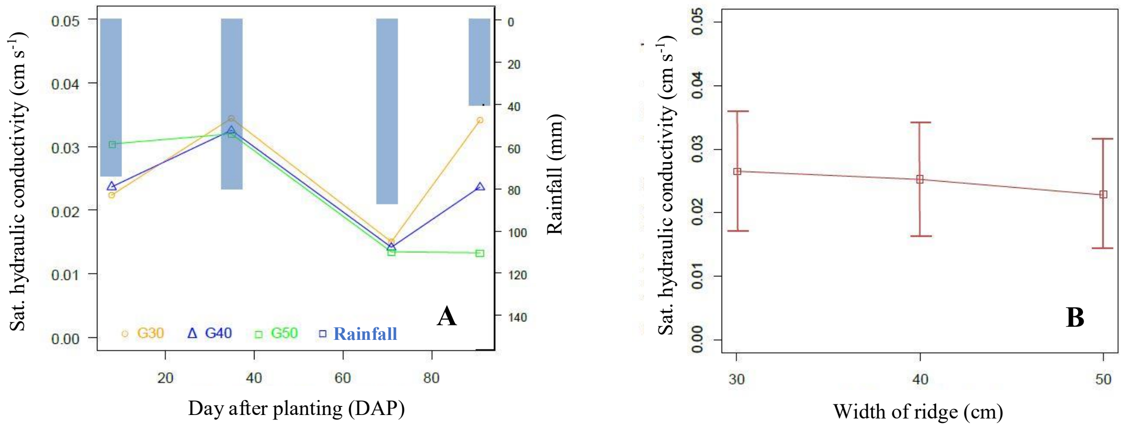

Figure 4. Soil saturated-hydraulic conductivity within various dimensions of the horizontal ridges.

More specifically, the K_s values tended to decrease with increasing the ridge widths (Fig. 4B). The 50-cm ridge width had the lowest K_s value compared to the 40-cm and 30-cm ridge widths, i.e., 0.023, 0.025, and 0.027 cm s^{-1}, respectively, although these values were not significantly different. The decreasing K_s value was closely related the increasing corresponded ρ_b value, in which higher the ρ_b value might reduce K_s value as well as percolation rate [22].

3.4. *Soil total-nitrogen (TN)*

In general, the average *TN* values within the horizontal ridges-organic-fertilizer applied potato land tended to decrease over a cultivation period (Fig. 5A). The highest and lowest *TN* values were found at 0 and 91 DAP, i.e., 4.22 – 5.23 ton ha^{-1} and 3.08 – 3.23 ton ha^{-1}, respectively. This might be related to the crop development that consumed more nitrogen especially at the initial stage [17,25]. Besides, the high rainfall induced the increase in θ values and the decrease in ρ_b and K_s values might affect more nitrogen loss through runoff or percolation [16,21]. More specifically, the 40-cm ridge width, however, was better in maintaining soil *TN* compared to the 30-cm and 50-cm ridge widths, at which after 35 DAP it shown to be slightly increased.

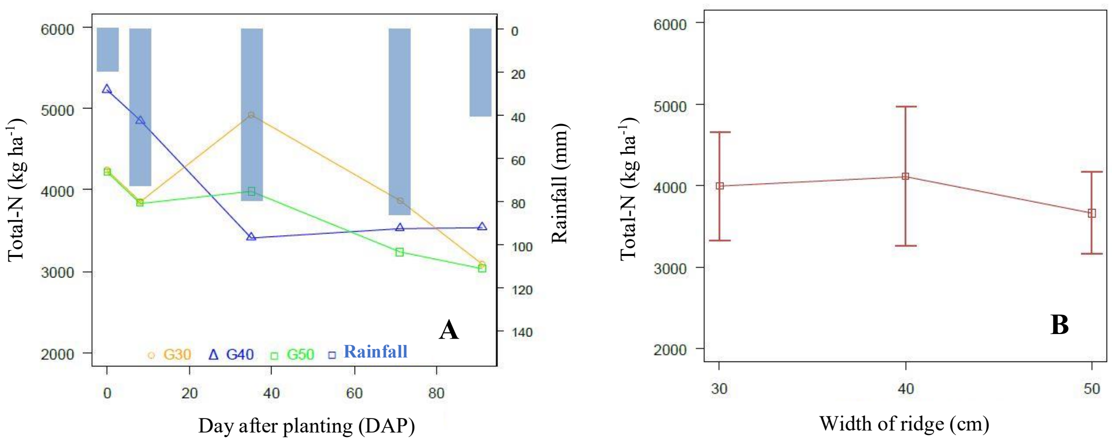

Figure 5. Soil total-nitrogen within various dimensions of the horizontal ridges.

Regarding the ridge widths, there was a tendency for the *TN* value to increase from 3.99 ton ha^{-1} (30-cm width) to 4.11 ton ha^{-1} (40-cm width), but then decrease to 3.66 ton ha^{-1} (50-cm width) (Fig. 5B), in which the values of two latter ridge widths were considerably insignificant. Among others, the highest capability of 40-cm ridge width in entrapping water and reducing runoff might be a reason for this results. Besides, this might be also related to higher the θ, ρ_b, and K_s within the 40-cm ridge profile compared to the 30-cm and 50-cm ridge widths. These higher values might then stimulate increasing water entrapment and percolation within the former ridge profile, hence reducing run off [22,23].

3.5. Soil total-phosphorus (TP)
Similar to *TN*, the average *TP* values within the horizontal ridges-organic-fertilizer applied potato land generally tended to decrease throughout a cultivation period (Fig. 6A), in which the highest and lowest values were encountered at 0 and 91 DAP, i.e., 2.39 – 3.85 ton ha^{-1} and 0.93 – 1.37 ton ha^{-1}, respectively. The nutrient uptake during crop development might trigger the phosphorus release from soil [17]. This was presumably stimulated by high rainfall rates as well as increasing θ values and decreasing ρ_b and K_s values, by which the phosphorus loss might be increased due to runoff or percolation [16,21]. Among others, the soil *TP* within 40-cm ridge width showed to be slightly increased after 35 DAP, indicated most effective in maintaining phosphorus content in soil.

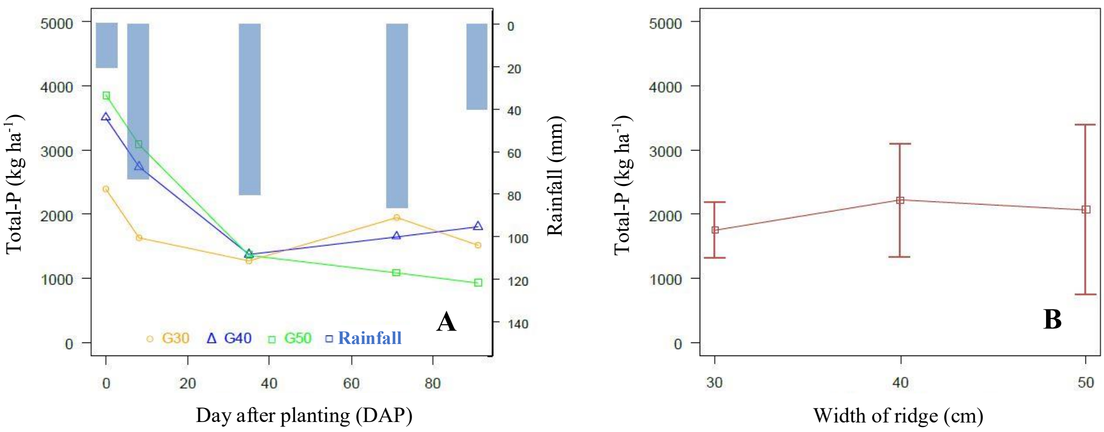

Figure 6. Soil total-phosphorus within various dimensions of the horizontal ridges.

Comparing the effects of three widths treated on nutrient availability (Fig. 6B), it was found that the 40-cm ridge width had highest capability to maintaining phosphorus content in soil, followed with the 50-cm (2.06 ton ha^{-1}) and 30-cm ridge width (1.75 ton ha^{-1}). This indicated that the 40-cm ridge width was most effective to entrapping rainfall and distributing water to deeper soil profile as well as to reduce runoff among others. Besides, the former ridge width had higher the θ, ρ_b, and K_s values, to which these capability were corresponded [22,23].

4. Conclusion
Dynamics of soil physical (θ, ρ_b, and K_s) and chemical (*TN* and *TP*) properties within various horizontal ridge dimensions and organic fertilizer applied potato land have been clearly identified. Over a cultivation period, the θ tended to increase with optimum value of 0.44 cm^3 cm^{-3} and the ρ_b tended to decrease with optimum values of 0.69 g cm^{-3}, while the K_s was shown to be fluctuated with optimum valued of 0.024 cm s^{-1}, regardless ridge dimensions. At the same period, there was tendency for *TN* and *TP* to decrease with optimum values of 3.94 and 2.14 ton ha^{-1}, respectively, regardless ridge dimensions. Concerning with the ridge dimensions, the 40-cm ridge width was most effective in maintaining both physical (θ, ρ_b, and K_s) and chemical (*TN* and *TP*) properties of soil with optimum values of 0.41 cm^3 cm^{-3}, 0.71 g cm^{-3}, 0.025 cm s^{-1}, and 4.11 and 2.21 ton ha^{-1}, respectively. In general, therefore, the 40-cm ridge width was considerably suitable for the sustainable potato cultivation in tropical highland.

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